# Physics

First examinations 2009

Diploma Programme

# Guide

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First examinations 2009

**International Baccalaureate Organization**

Buenos Aires Cardiff Geneva New York Singapore

**Diploma Programme**
**Physics—guide**

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# IBO mission statement

The International Baccalaureate Organization aims to develop inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through intercultural understanding and respect.

To this end the IBO works with schools, governments and international organizations to develop challenging programmes of international education and rigorous assessment.

These programmes encourage students across the world to become active, compassionate and lifelong learners who understand that other people, with their differences, can also be right.

# IB learner profile

The aim of all IB programmes is to develop internationally minded people who, recognizing their common humanity and shared guardianship of the planet, help to create a better and more peaceful world.

IB learners strive to be:

| | |
|---|---|
| **Inquirers** | They develop their natural curiosity. They acquire the skills necessary to conduct inquiry and research and show independence in learning. They actively enjoy learning and this love of learning will be sustained throughout their lives. |
| **Knowledgeable** | They explore concepts, ideas and issues that have local and global significance. In so doing, they acquire in-depth knowledge and develop understanding across a broad and balanced range of disciplines. |
| **Thinkers** | They exercise initiative in applying thinking skills critically and creatively to recognize and approach complex problems, and make reasoned, ethical decisions. |
| **Communicators** | They understand and express ideas and information confidently and creatively in more than one language and in a variety of modes of communication. They work effectively and willingly in collaboration with others. |
| **Principled** | They act with integrity and honesty, with a strong sense of fairness, justice and respect for the dignity of the individual, groups and communities. They take responsibility for their own actions and the consequences that accompany them. |
| **Open-minded** | They understand and appreciate their own cultures and personal histories, and are open to the perspectives, values and traditions of other individuals and communities. They are accustomed to seeking and evaluating a range of points of view, and are willing to grow from the experience. |
| **Caring** | They show empathy, compassion and respect towards the needs and feelings of others. They have a personal commitment to service, and act to make a positive difference to the lives of others and to the environment. |
| **Risk-takers** | They approach unfamiliar situations and uncertainty with courage and forethought, and have the independence of spirit to explore new roles, ideas and strategies. They are brave and articulate in defending their beliefs. |
| **Balanced** | They understand the importance of intellectual, physical and emotional balance to achieve personal well-being for themselves and others. |
| **Reflective** | They give thoughtful consideration to their own learning and experience. They are able to assess and understand their strengths and limitations in order to support their learning and personal development. |

# Contents



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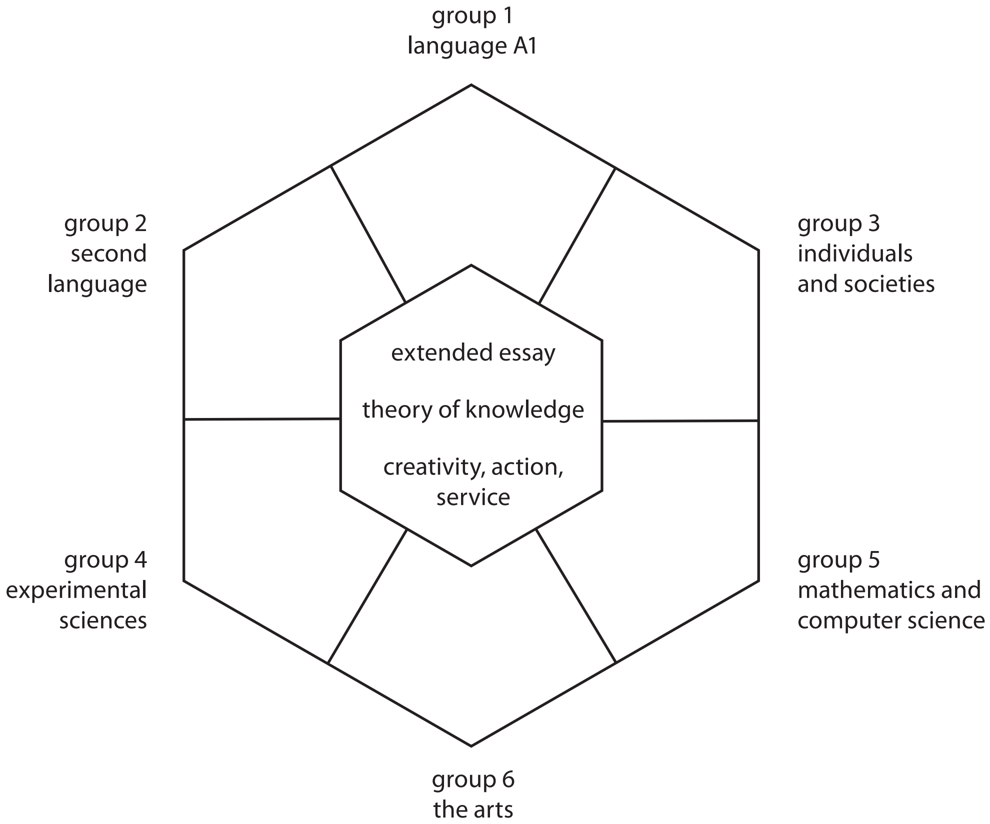
# The Diploma Programme

The Diploma Programme is a rigorous pre-university course of study designed for students in the 16 to 19 age range. It is a broad-based two-year course that aims to encourage students to be knowledgeable and inquiring, but also caring and compassionate. There is a strong emphasis on encouraging students to develop intercultural understanding, open-mindedness, and the attitudes necessary for them to respect and evaluate a range of points of view.

## The Diploma Programme hexagon

The course is presented as six academic areas enclosing a central core. It encourages the concurrent study of a broad range of academic areas. Students study: two modern languages (or a modern language and a classical language); a humanities or social science subject; an experimental science; mathematics; one of the creative arts. It is this comprehensive range of subjects that makes the Diploma Programme a demanding course of study designed to prepare students effectively for university entrance. In each of the academic areas students have flexibility in making their choices, which means they can choose subjects that particularly interest them and that they may wish to study further at university.

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## Choosing the right combination

Students are required to choose one subject from each of the six academic areas, although they can choose a second subject from groups 1 to 5 instead of a group 6 subject. Normally, three subjects (and not more than four) are taken at higher level (HL), and the others are taken at standard level (SL). The IBO recommends 240 teaching hours for HL subjects and 150 hours for SL. Subjects at HL are studied in greater depth and breadth than at SL.

At both levels, many skills are developed, especially those of critical thinking and analysis. At the end of the course, students' abilities are measured by means of external assessment. Many subjects contain some element of coursework assessed by teachers. The course is available for examinations in English, French and Spanish.

## The core of the hexagon

All Diploma Programme students participate in the three course requirements that make up the core of the hexagon. Reflection on all these activities is a principle that lies at the heart of the thinking behind the Diploma Programme.

The theory of knowledge (TOK) course encourages students to think about the nature of knowledge, to reflect on the process of learning in all the subjects they study as part of their Diploma Programme course, and to make connections across the academic areas. The extended essay, a substantial piece of writing of up to 4,000 words, enables students to investigate a topic of special interest that they have chosen themselves. It also encourages them to develop the skills of independent research that will be expected at university. Creativity, action, service (CAS) involves students in experiential learning through a range of artistic, sporting, physical and service activities.

## The IBO mission statement and the IB learner profile

The Diploma Programme aims to develop in students the knowledge, skills and attitudes they will need to fulfill the aims of the IBO, as expressed in the organization's mission statement and the learner profile. Teaching and learning in the Diploma Programme represent the reality in daily practice of the organization's educational philosophy.

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# Nature of group 4 subjects

## Difference between SL and HL

Group 4 students at standard level (SL) and higher level (HL) undertake a common core syllabus, a common internal assessment (IA) scheme and have some overlapping elements in the options studied. They are presented with a syllabus that encourages the development of certain skills, attributes and attitudes, as described in the "Objectives" section of this guide.

While the skills and activities of group 4 science subjects are common to students at both SL and HL, students at HL are required to study some topics in greater depth, to study additional topics and to study extension material of a more demanding nature in the common options. The distinction between SL and HL is one of breadth and depth.

## Group 4 subjects and prior learning

Past experience shows that students will be able to study a group 4 science subject at SL successfully with no background in, or previous knowledge of, science. Their approach to study, characterized by the specific IB learner profile attributes—inquirers, thinkers and communicators—will be significant here.

However, for most students considering the study of a group 4 subject at HL, while there is no intention to restrict access to group 4 subjects, some previous exposure to the specific group 4 subject would be necessary. Specific topic details are not specified but students who have undertaken the IB Middle Years Programme (MYP) or studied an international GCSE science subject would be well prepared. Other national science qualifications or a school-based science course would also be suitable preparation for study of a group 4 subject at HL.

## Group 4 subjects and the MYP

Students who have undertaken the MYP sciences, technology and mathematics courses will be well prepared for group 4 subjects. The MYP science objectives and assessment criteria A–F are aligned with the group 4 objectives and IA criteria, and allow for a smooth transition from the MYP to Diploma Programme. In particular, the "One world" objective in MYP sciences is further developed in group 4 science with the increased emphasis on aim 8—that is, to "raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology". There are specific references to aim 8 implications in assessment statements and teacher's notes in the syllabus details sections in all group 4 guides.

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# Group 4 subjects and TOK

In looking at the ways of knowing described in the *Theory of knowledge guide* (March 2006), scientists could legitimately claim that science encompasses all these. Driven by emotion, using sense perception, enhanced by technology and combined with reason, it communicates through language, principally the universal language of mathematics.

There is no one scientific method, in the strict Popperian sense, of gaining knowledge, of finding explanations for the behaviour of the natural world. Science works through a variety of approaches to produce these explanations, but they all rely on data from observations and experiments and have a common underpinning rigour, whether using inductive or deductive reasoning. The explanation may be in the form of a theory, sometimes requiring a model that contains elements not directly observable. Producing these theories often requires an imaginative, creative leap. Where such a predictive theoretical model is not possible, the explanation may consist of identifying a correlation between a factor and an outcome. This correlation may then give rise to a causal mechanism that can be experimentally tested, leading to an improved explanation. All these explanations require an understanding of the limitations of data, and the extent and limitations of our knowledge. Science requires freedom of thought and open-mindedness, and an essential part of the process of science is the way the international scientific community subjects the findings of scientists to intense critical scrutiny through the repetition of experiments and the peer review of results in scientific journals and at conferences. The syllabus details sections in the group 4 guides give references in teacher's notes to appropriate topics where these aspects of the scientific way of knowing can be addressed.

# Group 4 subjects and the international dimension

Science itself is an international endeavour—the exchange of information and ideas across national boundaries has been essential to the progress of science. This exchange is not a new phenomenon but it has accelerated in recent times with the development of information and communication technologies. Indeed, the idea that science is a Western invention is a myth—many of the foundations of modern-day science were laid many centuries before by Arabic, Indian and Chinese civilizations, among others. Teachers are encouraged to emphasize this contribution in their teaching of various topics, perhaps through the use of time-line web sites. The scientific method in its widest sense, with its emphasis on peer review, open-mindedness and freedom of thought, transcends politics, religion and nationality. Where appropriate within certain topics, the syllabus details sections in the group 4 guides contain assessment statements and teacher's notes illustrating the international aspects of science.

On an organizational level, many international bodies now exist to promote science. United Nations bodies such as UNESCO, UNEP and WMO, where science plays a prominent part, are well known, but in addition there are hundreds of international bodies representing every branch of science. The facilities for large-scale experimental science in, for example, particle physics and the Human Genome Project, are expensive and only joint ventures involving funding from many countries allow this to take place. The data from such research is shared by scientists worldwide. Group 4 students are encouraged to access the extensive web sites of these international scientific organizations to enhance their appreciation of the international dimension.

Increasingly, however, there is a recognition that many scientific problems, from climate change to AIDS, are international in nature and this has led to a global approach to research in many areas. The reports of the intergovernmental panel on climate change are a prime example of this. Some topics in the group 4 guides are specifically written to bring out this global research.

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On a practical level, the group 4 project (which all science students must undertake) mirrors the work of real scientists by encouraging collaboration between schools across the regions.

The power of scientific knowledge to transform societies is unparalleled. It has the potential to produce great universal benefits or to reinforce inequalities and cause harm to people and the environment. In line with the IBO mission statement, group 4 students need to be aware of the moral responsibility of scientists to ensure that scientific knowledge and data are available to all countries on an equitable basis and that they have the scientific capacity to use this for developing sustainable societies.

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# Curriculum model

A common curriculum model applies to all the Diploma Programme group 4 subjects: biology, chemistry, physics and design technology. (There are some differences in this model for design technology and these arise from the design project, which is a unique feature of this subject.) Students at both SL and HL study a core syllabus, and this is supplemented by the study of options. Students at HL also study additional higher level (AHL) material. Students at both SL and HL study two options. There are three kinds of options: those specific to SL students, those specific to HL students and those that can be taken by both SL and HL students.

Students at SL are required to spend 40 hours, and students at HL 60 hours, on practical/investigative work. This includes 10 hours for the group 4 project.

## SL group 4 curriculum model

| SL | Total teaching hours | 150 |
|---|---|---|
| **Theory** | | **110** |
| | Core | 80 |
| | Options | 30 |
| **Practical work** | | **40** |
| | Investigations | 30 |
| | Group 4 project | 10 |

## HL group 4 curriculum model

| HL | Total teaching hours | 240 |
|---|---|---|
| **Theory** | | **180** |
| | Core | 80 |
| | Additional higher level (AHL) | 55 |
| | Options | 45 |
| **Practical work** | | **60** |
| | Investigations | 50 |
| | Group 4 project | 10 |

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# Format of the syllabus details

Note: The order in which the syllabus content is presented is not intended to represent the order in which it should be taught.

The format of the syllabus details section of the group 4 guides is the same for each subject. The structure is as follows.

## Topics or options

Topics are numbered and options are indicated by a letter (for example, "Topic 6: Fields and forces", or "Option D: Relativity and particle physics").

## Sub-topics

Sub-topics are numbered and the estimated teaching time required to cover the material is indicated (for example, "6.1 Gravitational force and field (2 hours)"). The times are for guidance only and do not include time for practical/investigative work.

## Assessment statements (AS)

Assessment statements, which are numbered, are expressed in terms of the outcomes that are expected of students at the end of the course (for example, "6.1.1 State Newton's universal law of gravitation"). These are intended to prescribe to examiners what can be assessed by means of the written examinations. Each one is classified as objective 1, 2 or 3 (see the "Objectives" section) according to the command terms used (see the "Command terms" section). The objective levels are relevant for the examinations and for balance within the syllabus, while the command terms indicate the depth of treatment required for a given assessment statement. It is important that students are made aware of the meanings of the command terms because these will be used in examination questions. (When the command term "define" is used, the word(s) or phrase to be defined is in italics.)

## Teacher's notes

Teacher's notes, which are included alongside some assessment statements, provide further guidance to teachers.

They may also suggest ideas for the promotion of aim 7, aim 8, TOK and the international dimension (Int).

# Topic 1: Physics and physical measurement (5 hours)

Topic or option

## 1.1 The realm of physics

Sub-topic

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Range of magnitudes of quantities in our universe** | | | |
| 1.1.1 | State and compare quantities to the nearest order of magnitude. | 3 | |
| 1.1.2 | State the ranges of magnitude of distances, masses and times that occur in the universe, from smallest to greatest. | 1 | Distances: from $10^{-15}$ m to $10^{+25}$ m (sub-nuclear particles to extent of the visible universe).<br>Masses: from $10^{-30}$ kg to $10^{+50}$ kg (electron to mass of the universe).<br>Times: from $10^{-23}$ s to $10^{+18}$ s (passage of light across a nucleus to the age of the universe).<br>**Aim 7:** There are some excellent simulations to illustrate this.<br>**TOK:** This is a very stimulating area for a discussion of ways of knowing. |
| 1.1.3 | State ratios of quantities as differences of orders of magnitude. | 1 | For example, the ratio of the diameter of the hydrogen atom to its nucleus is about $10^5$, or a difference of five orders of magnitude. |
| 1.1.4 | Estimate approximate values of everyday quantities to one or two significant figures and/or to the nearest order of magnitude. | 2 | |

Assessment statement

Teacher's notes

Objective

## 1.2 Measurement and uncertainties

**2 hours**

**TOK:** Data and its limitations is a fruitful area for discussion.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The SI system of fundamental and derived units** | | | |
| 1.2.1 | State the fundamental units in the SI system. | 1 | Students need to know the following: kilogram, metre, second, ampere, mole and kelvin. |
| 1.2.2 | Distinguish between fundamental and derived units and give examples of derived units. | 2 | |


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# Aims

Through studying any of the group 4 subjects, students should become aware of how scientists work and communicate with each other. While the "scientific method" may take on a wide variety of forms, it is the emphasis on a practical approach through experimental work that distinguishes the group 4 subjects from other disciplines and characterizes each of the subjects within group 4.

It is in this context that all the Diploma Programme experimental science courses should aim to:

1. provide opportunities for scientific study and creativity within a global context that will stimulate and challenge students
2. provide a body of knowledge, methods and techniques that characterize science and technology
3. enable students to apply and use a body of knowledge, methods and techniques that characterize science and technology
4. develop an ability to analyse, evaluate and synthesize scientific information
5. engender an awareness of the need for, and the value of, effective collaboration and communication during scientific activities
6. develop experimental and investigative scientific skills
7. develop and apply the students' information and communication technology skills in the study of science
8. raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology
9. develop an appreciation of the possibilities and limitations associated with science and scientists
10. encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method.

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# Objectives

The objectives for all group 4 subjects reflect those parts of the aims that will be assessed. Wherever appropriate, the assessment will draw upon environmental and technological contexts and identify the social, moral and economic effects of science.

It is the intention of all the Diploma Programme experimental science courses that students achieve the following objectives.

1. Demonstrate an understanding of:
   a. scientific facts and concepts
   b. scientific methods and techniques
   c. scientific terminology
   d. methods of presenting scientific information.
2. Apply and use:
   a. scientific facts and concepts
   b. scientific methods and techniques
   c. scientific terminology to communicate effectively
   d. appropriate methods to present scientific information.
3. Construct, analyse and evaluate:
   a. hypotheses, research questions and predictions
   b. scientific methods and techniques
   c. scientific explanations.
4. Demonstrate the personal skills of cooperation, perseverance and responsibility appropriate for effective scientific investigation and problem solving.
5. Demonstrate the manipulative skills necessary to carry out scientific investigations with precision and safety.

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# Command terms

These command terms indicate the depth of treatment required for a given assessment statement. These command terms will be used in examination questions, so it is important that students are familiar with the following definitions.

## Objective 1

| | |
|---|---|
| **Define** | Give the precise meaning of a word, phrase or physical quantity. |
| **Draw** | Represent by means of pencil lines. |
| **Label** | Add labels to a diagram. |
| **List** | Give a sequence of names or other brief answers with no explanation. |
| **Measure** | Find a value for a quantity. |
| **State** | Give a specific name, value or other brief answer without explanation or calculation. |

## Objective 2

| | |
|---|---|
| **Annotate** | Add brief notes to a diagram or graph. |
| **Apply** | Use an idea, equation, principle, theory or law in a new situation. |
| **Calculate** | Find a numerical answer showing the relevant stages in the working (unless instructed not to do so). |
| **Describe** | Give a detailed account. |
| **Distinguish** | Give the differences between two or more different items. |
| **Estimate** | Find an approximate value for an unknown quantity. |
| **Identify** | Find an answer from a given number of possibilities. |
| **Outline** | Give a brief account or summary. |

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# Objective 3

| | |
|---|---|
| **Analyse** | Interpret data to reach conclusions. |
| **Comment** | Give a judgment based on a given statement or result of a calculation. |
| **Compare** | Give an account of similarities and differences between two (or more) items, referring to both (all) of them throughout. |
| **Construct** | Represent or develop in graphical form. |
| **Deduce** | Reach a conclusion from the information given. |
| **Derive** | Manipulate a mathematical relationship(s) to give a new equation or relationship. |
| **Design** | Produce a plan, simulation or model. |
| **Determine** | Find the only possible answer. |
| **Discuss** | Give an account including, where possible, a range of arguments for and against the relative importance of various factors, or comparisons of alternative hypotheses. |
| **Evaluate** | Assess the implications and limitations. |
| **Explain** | Give a detailed account of causes, reasons or mechanisms. |
| **Predict** | Give an expected result. |
| **Show** | Give the steps in a calculation or derivation. |
| **Sketch** | Represent by means of a graph showing a line and labelled but unscaled axes but with important features (for example, intercept) clearly indicated. |
| **Solve** | Obtain an answer using algebraic and/or numerical methods. |
| **Suggest** | Propose a hypothesis or other possible answer. |


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# Assessment outline

## SL assessment specifications

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| Component | Overall weighting (%) | Approximate weighting of objectives (%) | | Duration (hours) | Format and syllabus coverage |
|---|---|---|---|---|---|
| | | **1+2** | **3** | | |
| **Paper 1** | 20 | 20 | | ¾ | 30 multiple-choice questions on the core |
| **Paper 2** | 32 | 16 | 16 | 1¼ | Section A: one data-based question and several short-answer questions on the core (all compulsory)<br>Section B: one extended-response question on the core (from a choice of three) |
| **Paper 3** | 24 | 12 | 12 | 1 | Several short-answer questions in each of the two options studied (all compulsory) |

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# HL assessment specifications

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|---|

| Component | Overall weighting (%) | Approximate weighting of objectives (%) | | Duration (hours) | Format and syllabus coverage |
|---|---|---|---|---|---|
| | | **1+2** | **3** | | |
| **Paper 1** | 20 | 20 | | 1 | 40 multiple-choice questions (±15 common to SL plus about five more on the core and about 20 more on the AHL) |
| **Paper 2** | 36 | 18 | 18 | 2¼ | Section A: one data-based question and several short-answer questions on the core and the AHL (all compulsory)<br>Section B: two extended-response questions on the core and the AHL (from a choice of four) |
| **Paper 3** | 20 | 10 | 10 | 1¼ | Several short-answer questions and one extended-response question in each of the two options studied (all compulsory) |

In addition to addressing objectives 1, 2 and 3, the internal assessment scheme for both SL and HL addresses objective 4 (personal skills) using the personal skills criterion to assess the group 4 project, and objective 5 (manipulative skills) using the manipulative skills criterion to assess practical work. For both SL and HL, calculators are not permitted in paper 1 but are required in papers 2 and 3.

**A clean copy of the *Physics data booklet* is required for papers 1, 2 and 3 at both SL and HL.**

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# External assessment

The external assessment consists of three written papers.

## Paper 1

Paper 1 is made up of multiple-choice questions that test knowledge of the core only for students at SL and the core and AHL material for students at HL. The questions are designed to be short, one- or two-stage problems that address objectives 1 and 2 (see the "Objectives" section). No marks are deducted for incorrect responses. Calculators are not permitted, but students are expected to carry out simple calculations.

## Paper 2

Paper 2 tests knowledge of the core only for students at SL and the core and AHL material for students at HL. The questions address objectives 1, 2 and 3 and the paper is divided into two sections.

In section A, there is a data-based question that requires students to analyse a given set of data. The remainder of section A is made up of short-answer questions.

In section B, students at SL are required to answer one question from a choice of three, and students at HL are required to answer two questions from a choice of four. These extended-response questions may involve writing a number of paragraphs, solving a substantial problem, or carrying out a substantial piece of analysis or evaluation. A calculator is required for this paper.

## Paper 3

Paper 3 tests knowledge of the options and addresses objectives 1, 2 and 3. Students at SL are required to answer several short-answer questions in each of the two options studied. Students at HL are required to answer several short-answer questions and an extended-response question in each of the two options studied. A calculator is required for this paper.

**A clean copy of the *Physics data booklet* is required for papers 1, 2 and 3 at both SL and HL.**

Note: Wherever possible, teachers should use, and encourage students to use, the Système International d'Unités (International System of Units—SI units).

# Practical work and internal assessment

## General introduction

The internal assessment (IA) requirements are the same for all group 4 subjects, with the exception of design technology, which has an additional element. The IA, worth 24% of the final assessment (or 36% for design technology), consists of an interdisciplinary project, a mixture of short- and long-term investigations (such as practicals and subject-specific projects) and, for design technology only, the design project.

Student work is internally assessed by the teacher and externally moderated by the IBO. The performance in IA at both SL and HL is marked against assessment criteria, with each criterion having a maximum mark of 6.

## Rationale for practical work

Although the requirements for IA are mainly centred on the assessment of practical skills, the different types of experimental work that a student may engage in serve other purposes, including:

- illustrating, teaching and reinforcing theoretical concepts
- developing an appreciation of the essential hands-on nature of scientific work
- developing an appreciation of the benefits and limitations of scientific methodology.

Therefore, there may be good justification for teachers to conduct further experimental work beyond that required for the IA scheme.

## Practical scheme of work

The practical scheme of work (PSOW) is the practical course planned by the teacher and acts as a summary of all the investigative activities carried out by a student. Students at SL and HL in the same subject may carry out some of the same investigations.

### Syllabus coverage

The range of investigations carried out should reflect the breadth and depth of the subject syllabus at each level, but it is not necessary to carry out an investigation for every syllabus topic. However, all students must participate in the group 4 project and the IA activities should ideally include a spread of content material from the core, options and, where relevant, AHL material. A minimum number of investigations to be carried out is not specified.

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## Choosing investigations

Teachers are free to formulate their own practical schemes of work by choosing investigations according to the requirements outlined. Their choices should be based on:

- subjects, levels and options taught
- the needs of their students
- available resources
- teaching styles.

Each scheme must include some complex investigations that make greater conceptual demands on students. A scheme made up entirely of simple experiments, such as ticking boxes or exercises involving filling in tables, will not provide an adequate range of experience for students.

Teachers are encouraged to use the online curriculum centre (OCC) to share ideas about possible investigations by joining in the discussion forums and adding resources in the subject home pages.

> Note: Any investigation or part investigation that is to be used to assess students should be specifically designed to match the relevant assessment criteria.

## Flexibility

The IA model is flexible enough to allow a wide variety of investigations to be carried out. These could include:

- short laboratory practicals over one or two lessons and long-term practicals or projects extending over several weeks
- computer simulations
- data-gathering exercises such as questionnaires, user trials and surveys
- data-analysis exercises
- general laboratory work and fieldwork.

## The group 4 project

The group 4 project is an interdisciplinary activity in which all Diploma Programme science students must participate. The intention is that students from the different group 4 subjects analyse a common topic or problem. The exercise should be a collaborative experience where the emphasis is on the **processes** involved in scientific investigation rather than the **products** of such investigation.

In most cases all students in a school would be involved in the investigation of the same topic. Where there are large numbers of students, it is possible to divide them into several smaller groups containing representatives from each of the science subjects. Each group may investigate the same topic or different topics—that is, there may be several group 4 projects in the same school.

# Practical work documentation

Details of an individual student's practical scheme of work are recorded on **form 4/PSOW** provided in section 4 of the *Vade Mecum*. Electronic versions may be used as long as they include all necessary information. In addition, the laboratory work corresponding to the best two marks achieved by each student when assessed using the internal assessment criteria (design, data collection and processing, and conclusion and evaluation) and the instructions given by the teacher for the laboratory work must be retained for possible inclusion in the sample work sent to an internal assessment moderator.

# Time allocation for practical work

The recommended teaching times for all Diploma Programme courses are 150 hours at SL and 240 hours at HL. Students at SL are required to spend 40 hours, and students at HL 60 hours, on practical activities (excluding time spent writing up work). These times include 10 hours for the group 4 project. Only 2–3 hours of investigative work can be carried out after the deadline for submitting work to the moderator and still be counted in the total number of hours for the practical scheme of work.

> Note: For design technology, students at SL are required to spend 55 hours, and students at HL 81 hours, on practical activities.

Only some of the 40/60 hours of practical work need be allocated to the practical work that is assessed using the IA criteria. This will normally be done during the latter part of the course when students have become more familiar with the criteria and can be assessed in complex practical work.

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# Guidance and authenticity

All students should be familiar with the requirements for IA. It should be made clear to them that they are entirely responsible for their own work. It is helpful if teachers encourage students to develop a sense of responsibility for their own learning so that they accept a degree of ownership and take pride in their own work.

In responding to specific questions from students concerning investigations, teachers should (where appropriate) guide students into more productive routes of inquiry rather than respond with a direct answer. As part of the learning process, teachers can give general advice to students on a first draft of their work for IA. However, constant drafting and redrafting is not allowed and the next version handed to the teacher after the first draft must be the final one. This is marked by the teacher using the IA criteria. It is useful to annotate this work with the levels awarded for each aspect—"c" for complete, "p" for partial and "n" for not at all, to assist the moderator should the work be selected as part of the sample.

**In assessing student work using the IA criteria, teachers should only mark and annotate the final draft.**

When completing an investigation outside the classroom, students should work independently. Teachers are required to ensure that work submitted is the student's own. If any doubt exists, authenticity may be checked by one or more of the following methods.

- Discussion with the student
- Asking the student to explain the methods used and to summarize the results
- Asking the student to repeat the investigation

Teachers are required to sign the IA coversheet to confirm that the work of each student is his or her own unaided work.

# Safety

While teachers are responsible for following national or local guidelines, which may differ from country to country, attention should be given to the mission statement below, which was developed by the International Council of Associations for Science Education (ICASE) Safety Committee.

## ICASE Safety Committee

### Mission statement

> The mission of the ICASE Safety Committee is to promote good quality, exciting practical science, which will stimulate students and motivate their teachers, in a safe and healthy learning environment. In this way, all individuals (teachers, students, laboratory assistants, supervisors, visitors) involved in science education are entitled to work under the safest possible practicable conditions in science classrooms and laboratories. Every reasonable effort needs to be made by administrators to provide and maintain a safe and healthy learning

environment and to establish and require safe methods and practices at all times. Safety rules and regulations need to be developed and enforced for the protection of those individuals carrying out their activities in science classrooms and laboratories, and experiences in the field. Alternative science activities are encouraged in the absence of sufficiently safe conditions.

It is a basic responsibility of everyone involved to make safety and health an ongoing commitment. Any advice given will acknowledge the need to respect the local context, the varying educational and cultural traditions, the financial constraints and the legal systems of differing countries.

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# Internal assessment criteria

## General information

The method of assessment used for internal assessment is criterion-related. That is to say, the method of assessment judges each student in relation to identified assessment criteria and not in relation to the work of other students.

The internal assessment component in all group 4 courses is assessed according to sets of assessment criteria and achievement level descriptors. The internal assessment criteria are for the use of teachers.

- For each assessment criterion, there are a number of descriptors that each describes a specific level of achievement.
- The descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

## Using the internal assessment criteria

Teachers should judge the internal assessment exercise against the descriptors for each criterion. The same internal assessment criteria are used for both SL and HL.

- The aim is to find, for each criterion, the descriptor that conveys most adequately the achievement level attained by the student. The process, therefore, is one of approximation. In the light of any one criterion, a student’s work may contain features denoted by a high achievement level descriptor combined with features appropriate to a lower one. A professional judgment should be made in identifying the descriptor that approximates most closely to the work.
- Having scrutinized the work to be assessed, the descriptors for each criterion should be read, starting with level 0, until one is reached that describes an achievement level that the work being assessed does not match as well as the previous level. The work is, therefore, best described by the preceding achievement level descriptor and this level should be recorded. Only whole numbers should be used, not partial points such as fractions or decimals.
- The highest descriptors do not imply faultless performance and moderators and teachers should not hesitate to use the extremes, including zero, if they are appropriate descriptions of the work being assessed.
- Descriptors should not be considered as marks or percentages, although the descriptor levels are ultimately added together to obtain a total. It should not be assumed that there are other arithmetical relationships; for example, a level 2 performance is not necessarily twice as good as a level 1 performance.
- A student who attains a particular achievement level in relation to one criterion will not necessarily attain similar achievement levels in relation to the others. It should not be assumed that the overall assessment of the students will produce any particular distribution of scores.
- The assessment criteria should be available to students at all times.

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# Criteria and aspects

There are five assessment criteria that are used to assess the work of both SL and HL students.

- Design—D
- Data collection and processing—DCP
- Conclusion and evaluation—CE
- Manipulative skills—MS
- Personal skills—PS

The first three criteria—design (D), data collection and processing (DCP) and conclusion and evaluation (CE)—are each assessed twice.

Manipulative skills (MS) is assessed summatively over the whole course and the assessment should be based on a wide range of manipulative skills.

Personal skills (PS) is assessed once only and this will be during the group 4 project.

Each of the assessment criteria can be separated into three **aspects** as shown in the following sections. Descriptions are provided to indicate what is expected in order to meet the requirements of a given aspect **completely (c)** and **partially (p)**. A description is also given for circumstances in which the requirements are not satisfied, **not at all (n)**.

A **"complete"** is awarded 2 marks, a **"partial"** 1 mark and a **"not at all"** 0 marks.

The maximum mark for each criterion is 6 (representing three "completes").

| | |
|---|---|
| D | $\times 2 = 12$ |
| DCP | $\times 2 = 12$ |
| CE | $\times 2 = 12$ |
| MS | $\times 1 = 6$ |
| PS | $\times 1 = 6$ |

This makes a total mark out of 48.

The marks for each of the criteria are added together to determine the final mark out of 48 for the IA component. This is then scaled at IBCA to give a total out of 24%.

General regulations and procedures relating to IA can be found in the *Vade Mecum* for the year in which the IA is being submitted.

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## Design

| Levels/marks | Aspect 1 | Aspect 2 | Aspect 3 |
|---|---|---|---|
| | **Defining the problem and selecting variables** | **Controlling variables** | **Developing a method for collection of data** |
| **Complete/2** | Formulates a focused problem/research question and identifies the relevant variables. | Designs a method for the effective control of the variables. | Develops a method that allows for the collection of sufficient relevant data. |
| **Partial/1** | Formulates a problem/ research question that is incomplete **or** identifies only some relevant variables. | Designs a method that makes some attempt to control the variables. | Develops a method that allows for the collection of insufficient relevant data. |
| **Not at all/0** | Does not identify a problem/research question **and** does not identify any relevant variables. | Designs a method that does not control the variables. | Develops a method that does not allow for any relevant data to be collected. |

## Data collection and processing

| Levels/marks | Aspect 1 | Aspect 2 | Aspect 3 |
|---|---|---|---|
| | **Recording raw data** | **Processing raw data** | **Presenting processed data** |
| **Complete/2** | Records appropriate quantitative and associated qualitative raw data, including units and uncertainties where relevant. | Processes the quantitative raw data correctly. | Presents processed data appropriately and, where relevant, includes errors and uncertainties. |
| **Partial/1** | Records appropriate quantitative and associated qualitative raw data, but with some mistakes or omissions. | Processes quantitative raw data, but with some mistakes and/or omissions. | Presents processed data appropriately, but with some mistakes and/or omissions. |
| **Not at all/0** | Does not record any appropriate quantitative raw data **or** raw data is incomprehensible. | No processing of quantitative raw data is carried out **or** major mistakes are made in processing. | Presents processed data inappropriately **or** incomprehensibly. |

## Conclusion and evaluation

| Levels/marks | Aspect 1 | Aspect 2 | Aspect 3 |
|---|---|---|---|
| | Concluding | Evaluating procedure(s) | Improving the investigation |
| **Complete/2** | States a conclusion, with justification, based on a reasonable interpretation of the data. | Evaluates weaknesses and limitations. | Suggests realistic improvements in respect of identified weaknesses and limitations. |
| **Partial/1** | States a conclusion based on a reasonable interpretation of the data. | Identifies some weaknesses and limitations, but the evaluation is weak or missing. | Suggests only superficial improvements. |
| **Not at all/0** | States no conclusion **or** the conclusion is based on an unreasonable interpretation of the data. | Identifies irrelevant weaknesses and limitations. | Suggests unrealistic improvements. |

## Manipulative skills (assessed summatively)

This criterion addresses objective 5.

| Levels/marks | Aspect 1 | Aspect 2 | Aspect 3 |
|---|---|---|---|
| | Following instructions* | Carrying out techniques | Working safely |
| **Complete/2** | Follows instructions accurately, adapting to new circumstances (seeking assistance when required). | Competent and methodical in the use of a range of techniques and equipment. | Pays attention to safety issues. |
| **Partial/1** | Follows instructions but requires assistance. | Usually competent and methodical in the use of a range of techniques and equipment. | Usually pays attention to safety issues. |
| **Not at all/0** | Rarely follows instructions **or** requires constant supervision. | Rarely competent and methodical in the use of a range of techniques and equipment. | Rarely pays attention to safety issues. |

*Instructions may be in a variety of forms: oral, written worksheets, diagrams, photographs, videos, flow charts, audio tapes, models, computer programs, and so on, and need not originate from the teacher.

See "The group 4 project" section for the personal skills criterion.

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# Clarifications of the IA criteria

## Design

### Aspect 1: defining the problem and selecting variables

It is essential that teachers give an open-ended problem to investigate, where there are several independent variables from which a student could choose one that provides a suitable basis for the investigation. This should ensure that a range of plans will be formulated by students and that there is sufficient scope to identify both independent and controlled variables.

Although the general aim of the investigation may be given by the teacher, students must identify a focused problem or specific research question. Commonly, students will do this by modifying the general aim provided and indicating the variable(s) chosen for investigation.

The teacher may suggest the general research question only. Asking students to investigate some physical property of a bouncing ball, where no variables are given, would be an acceptable teacher prompt. This could be focused by the student as follows: "I will investigate the relationship between the rebound height and the drop height of a bouncing ball."

Alternatively, the teacher may suggest the general research question and specify the dependent variable. An example of such a teacher prompt would be to ask the student to investigate the deflection of a cantilever. This could then be focused by the student as follows: "I propose to investigate how the deflection of a cantilever is affected by the load attached to one end." It is not sufficient for the student merely to restate the research question provided by the teacher.

Variables are factors that can be measured and/or controlled. Independent variables are those that are manipulated, and the result of this manipulation leads to the measurement of the dependent variable. A controlled variable is one that should be held constant so as not to obscure the effect of the independent variable on the dependent variable.

The variables need to be explicitly identified by the student as the dependent (measured), independent (manipulated) and controlled variables (constants). Relevant variables are those that can reasonably be expected to affect the outcome. For example, in the investigation of the bouncing ball, the drop height would be the independent variable and the rebound height would be the dependent variable. Controlled variables would include using the same ball and the same surface for all measurements.

Students should **not** be:

- given a focused research question
- told the outcome of the investigation
- told which independent variable to select
- told which variables to hold constant.

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### Aspect 2: controlling variables

"Control of variables" refers to the manipulation of the independent variable and the attempt to maintain the controlled variables at a constant value. The method should include explicit reference to how the control of variables is achieved. If the control of variables is not practically possible, some effort should be made to monitor the variable(s).

Students should **not** be told:

- which apparatus to select
- the experimental method.

### Aspect 3: developing a method for collection of data

The definition of "sufficient relevant data" depends on the context. The planned investigation should anticipate the collection of sufficient data so that the aim or research question can be suitably addressed and an evaluation of the reliability of the data can be made.

The collection of sufficient relevant data usually implies repeating measurements. For example, to find the period of a pendulum, the time for a number of oscillations is measured in order to find the time for one oscillation. Measuring the time for just one oscillation for a given pendulum length would not earn a "complete". Or, for example, measuring the time for a ball to roll a given distance down an inclined plane can be repeated a number of times and then an average time can be determined.

The data range and the amount of data in that range are also important. For example, in the pendulum experiment, a length range of 10 cm to 100 cm might be used, but measuring the period for only three points within that range would not be appropriate. Similarly, measuring the period for 10 data points in a range from 80 cm to 90 cm would also be inappropriate.

Students should **not** be told:

- how to collect the data
- how much data to collect.

## Data collection and processing

Ideally, students should work on their own when collecting data.

When data collection is carried out in groups, the actual recording and processing of data should be independently undertaken if this criterion is to be assessed.

### Aspect 1: recording raw data

Raw data is the actual data measured. This may include associated qualitative data. It is permissible to convert handwritten raw data into word-processed form. The term "quantitative data" refers to numerical measurements of the variables associated with the investigation. Associated qualitative data are considered to be those observations that would enhance the interpretation of results.

Uncertainties are associated with all raw data and an attempt should always be made to quantify uncertainties. For example, when students say there is an uncertainty in a stopwatch measurement because of reaction time, they must estimate the magnitude of the uncertainty. Within tables of quantitative data, columns should be clearly annotated with a heading, units and an indication of the uncertainty of measurement. The uncertainty need not be the same as the manufacturer's stated precision of the measuring device used. Significant digits in the data and the uncertainty in the data must be consistent.

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This applies to all measuring devices, for example, digital meters, stopwatches, and so on. The number of significant digits should reflect the precision of the measurement.

There should be no variation in the precision of raw data. For example, the same number of decimal places should be used. For data derived from processing raw data (for example, means), the level of precision should be consistent with that of the raw data.

Students should **not** be told how to record the raw data. For example, they should not be given a pre-formatted table with any columns, headings, units or uncertainties.

## Aspect 2: processing raw data

Data processing involves, for example, combining and manipulating raw data to determine the value of a physical quantity (such as adding, subtracting, squaring, dividing), and taking the average of several measurements and transforming data into a form suitable for graphical representation. It might be that the data is already in a form suitable for graphical presentation, for example, light absorbance readings plotted against time readings. If the raw data is represented in this way and a best-fit line graph is drawn and the gradient determined, then the raw data has been processed. Plotting raw data (without a graph line) does not constitute processing data.

The recording and processing of data may be shown in one table provided they are clearly distinguishable.

Most processed data will result in the drawing of a graph showing the relationship between the independent and dependent variables.

Students should **not** be told:

- how to process the data
- what quantities to graph/plot.

## Aspect 3: presenting processed data

When data is processed, the uncertainties associated with the data must also be considered. If the data is combined and manipulated to determine the value of a physical quantity (for example, specific heat capacity), then the uncertainties in the data must be propagated (see sub-topic 1.2). Calculating the percentage difference between the measured value and the literature value does not constitute error analysis. The uncertainties associated with the raw data must be taken into account.

Graphs need to have appropriate scales, labelled axes with units, and accurately plotted data points with a suitable best-fit line or curve (not a scattergraph with data-point to data-point connecting lines).

In order to fulfill aspect 3 completely, students should include a treatment of uncertainties and errors with their processed data.

The complete fulfillment of aspect 3 requires the students to:

- include uncertainty bars where significant
- explain where uncertainties are not significant
- draw lines of minimum and maximum gradients
- determine the uncertainty in the best straight-line gradient.

See the treatment of uncertainties and errors in sub-topic 1.2 of this guide.

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# Conclusion and evaluation

## Aspect 1: concluding

Conclusions that are supported by the data are acceptable even if they appear to contradict accepted theories. However, the conclusion must take into account any systematic or random errors and uncertainties. A percentage error should be compared with the total estimated random error as derived from the propagation of uncertainties.

In justifying their conclusion, students should discuss whether systematic error or further random errors were encountered. The direction of any systematic errors should be appreciated. Analysis may include comparisons of different graphs or descriptions of trends shown in graphs. The explanation should contain observations, trends or patterns revealed by the data.

When measuring an already known and accepted value of a physical quantity, students should draw a conclusion as to their confidence in their result by comparing the experimental value with the textbook or literature value. The literature consulted should be fully referenced.

## Aspect 2: evaluating procedure(s)

The design and method of the investigation must be commented upon as well as the quality of the data. The student must not only list the weaknesses but must also appreciate how significant the weaknesses are. Comments about the precision and accuracy of the measurements are relevant here. When evaluating the procedure used, the student should specifically look at the processes, use of equipment and management of time.

## Aspect 3: improving the investigation

Suggestions for improvement should be based on the weaknesses and limitations identified in aspect 2. Modifications to the experimental techniques and the data range can be addressed here. The modifications should address issues of precision, accuracy and reproducibility of the results. Students should suggest how to reduce random error, remove systematic error and/or obtain greater control of variables. The modifications proposed should be realistic and clearly specified. It is not sufficient to state generally that more precise equipment should be used.

# Manipulative skills

(This criterion must be assessed summatively.)

## Aspect 1: following instructions

Indications of manipulative ability are the amount of assistance required in assembling equipment, the orderliness of carrying out the procedure(s) and the ability to follow the instructions accurately. The adherence to safe working practices should be apparent in all aspects of practical activities.

A wide range of complex tasks should be included in the scheme of work.

## Aspect 2: carrying out techniques

It is expected that students will be exposed to a variety of different investigations during the course that enables them to experience a variety of experimental situations.

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### Aspect 3: working safely

The student's approach to safety during investigations in the laboratory or in the field must be assessed. Nevertheless, the teacher must not put students in situations of unacceptable risk.

The teacher should judge what is acceptable and legal under local regulations and with the facilities available. See the "Safety" section in this guide under "Guidance and authenticity".

## Personal skills

Note: The personal skills criterion is assessed in the group 4 project only and is to be found in "The group 4 project" section.

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# The use of ICT

In accordance with aim 7—that is, to “develop and apply the students’ information and communication technology skills in the study of science”—the use of information and communication technology (ICT) is encouraged in practical work throughout the course, whether the investigations are assessed using the IA criteria or otherwise.

## Section A: use of ICT in assessment

Data-logging software may be used in experiments/investigations assessed using the IA criteria provided that the following principle is applied.

The student’s contribution to the experiment must be evident so that this alone can be assessed by the teacher. This student’s contribution can be in the selection of settings used by the data-logging and graphing equipment, or can be demonstrated in subsequent stages of the experiment.

(When data logging is used, raw data is defined as any data produced by software and extracted by the student from tables or graphs to be subsequently processed by the student.)

The following categories of experiments exemplify the application of this principle.

### 1. Data logging within a narrowly focused task

Data-logging software may be used to perform a traditional experiment in a new way.

**Use of data-logging software is appropriate with respect to assessment if the student decides and inputs most of the relevant software settings.** For example, suppose that a student wants to measure the acceleration of a trolley as it moves down an inclined plane. A sonic motion detector is used to gather data and generate graphs. This investigation can be both appropriate and inappropriate for IA marking, depending on the contributions of the student.

This investigation would be appropriate for IA if the student contributes to the setting-up of the equipment and software by the selection of parameters and the overall presentation of the data and results. For instance, the student might calibrate the sonic detector before running the experiment. The detector uses the speed of sound, and this varies depending on the classroom conditions, such as temperature. Next, the student may decide on the sampling rate and its duration time. When there is no motion, the read-out of the sonic detector exhibits some random noise. The student uses the range of this noise to estimate an uncertainty in the raw data. Knowing that the computer generates data for position, speed and acceleration as functions of time by using consecutive measurements of the reflected or echo time and the known speed of sound, the student accepts the distance and speed measured but not the acceleration measurement. The student uses the experimental data to generate a speed *versus* time graph, and from the gradient of this graph the average acceleration is determined. This method eliminates systematic errors from the data and yields a more reliable result. Uncertainties and significant figures are all accounted for. The student’s work is appropriate for IA marking.

**Data logging in which the software automatically determines the various settings and generates the data tables and graphs is inappropriate with regard to assessment.**

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For example, the same experimental investigation could be carried out with little or no student input and as such would be inappropriate for IA marking. Nonetheless, it would provide the student with data-logging experience and, as such, it would be a worthwhile investigation. Here, for instance, the parameters of the software program would be pre-set, no calibration would be made, and no attention to significant figures or uncertainties would be made. After releasing the trolley and starting the data-logging software, the computer automatically generates graphs of position, speed and acceleration, all as functions of time. The student would accept this output without question.

If the experiment is suitable for assessment the following guidelines must be followed for the DCP criterion.

### Data collection and processing: aspect 1

Students may present raw data collected using data logging as long as they are responsible for the majority of software settings. The numerical raw data may be presented as a table, or, where a large amount of data has been generated, by graphical means. Students must annotate the data correctly, for example, by means of table or graph titles, columns or graph axes labelled with units, indications of uncertainties, associated qualitative observations, and so on.

The number of decimal places used in recorded data should not exceed that expressed by the sensitivity of the instrument used. In the case of electronic probes used in data logging, students will be expected to record the sensitivity of the instrument.

### Data collection and processing: aspects 2 and 3

Use of software for graph drawing is appropriate as long as the student is responsible for most of the decisions, such as:

- what to graph
- selection of quantities for axes
- appropriate units
- graph title
- appropriate scale
- how to graph, for example, linear graph line and not scatter.

> Note: A computer-calculated gradient is acceptable.

Analysis carried out using calculators or calculations using spreadsheets are acceptable provided that the student selects the data to be processed and chooses the method of processing. In both cases, the student must show one example in the written text. For example, the student must quote the formula used by or entered into a calculator and define the terms used, or the student must write the formula used in a spreadsheet if it is not a standard part of the program's menu of functions (for example, mean, standard deviation).

## 2. Data logging in an open-ended investigation

Data-logging software can enhance data collection and transform the sort of investigations possible. In this case fully automated data-logging software is appropriate with regard to assessment **if** it is used to enable a broader, complex investigation to be undertaken where students can develop a range of responses involving independent decision-making.

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For example, consider an open-ended investigation into the phenomenon of a bouncing ball. The student designed the investigation making extensive use of ICT. The student's work could be assessed for design and DCP as follows.

### Design: aspect 1

The teacher prompt was to investigate a bouncing ball. The student then came up with a research question: "How does the rebound height of a bouncing ball vary with the number of bounces?"

The student identified the controlled variables as the initial drop height, the ball and the surface with which the ball collides, the independent variable as the number of bounces, and the dependent variable as the rebound height.

### Design: aspect 2

To qualify for assessment of aspect 2, the student needs to describe an effective method to control the variables.

The student uses a microphone with an interface connected to a computer in order to record the sound intensity of the bouncing ball as a function of time. The software program was fully automatic and all the settings were pre-set. From the generated graph of sound intensity against time, information about the bounce number will be identified and the time interval between bounces can be calculated. Using the equations of motion, the time interval is used to find the rebound height for consecutive bounces. Other details of the method were discussed and aspect 2 was assessed here.

### Design: aspect 3

The student carried out a preliminary experiment dropping the ball from different heights to identify an acceptable drop height that produces a reasonable data set. No ICT was used here. The student decided on about 20 bounces and a drop height of 15 cm.

The student repeated the experiment twice, producing three sets of data, to assess reliability.

### Data collection and processing: aspect 1

The first graph produced was intensity against time. This was not assessed under the IA criteria because the software automatically generated it. The student then used the time and the bounce number from this graph to produce a data table containing the time that each consecutive bounce occurred and the bounce number. This data table included the units, significant figures, uncertainties and repeats. This was assessed under DCP aspect 1.

### Data collection and processing: aspect 2

The student then produced a third column in the data table where the time interval between consecutive bounces was calculated and the rebound height of each bounce was calculated (using half the interval time). The results included uncertainties. This was assessed as processed data.

### Data collection and processing: aspect 3

The student inputs information from the previous graph into graphing software to construct a plot of rebound height against bounce number, including uncertainty bars constructed by the student for one of the axes. This graph appeared to reveal an exponential decay, and so the student constructed another graph, this time using logarithms. Uncertainty bars were drawn and maximum and minimum gradients were drawn. The gradient of the best-fit line was identified as the decay constant and a half-life was calculated. The maximum and minimum gradients were then used to express an uncertainty for the decay constant. The result showed exponential decay for the bouncing ball when compared to bounce number. The last two graphs were assessed under DCP aspect 3.

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# Section B: use of ICT in non-assessed practical work

It is not necessary to use ICT in assessed investigations but, in order to carry out aim 7 in practice, students will be required to use each of the following software applications at least once during the course.

- Data logging in an experiment
- Software for graph plotting
- A spreadsheet for data processing
- A database
- Computer modelling/simulation

There are many examples of the above in the ICT resources for biology, chemistry and physics on the OCC.

Apart from sensors for data logging, all the other components involve software that is free and readily available on the Internet. As students only need to use data-logging software and sensors once in the course, class sets are not required.

The use of each of the above five ICT applications by students would be authenticated by means of entries in the students' practical scheme of work, form 4/PSOW. For example, if a student used a spreadsheet in an investigation, this should be recorded on form 4/PSOW. Any other applications of ICT can also be recorded on form 4/PSOW.

# The group 4 project

## Summary of the group 4 project

The group 4 project is a collaborative activity where students from different group 4 subjects work together on a scientific or technological topic, allowing for concepts and perceptions from across the disciplines to be shared in line with aim 10—that is, to "encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method". The project can be practically or theoretically based. Collaboration between schools in different regions is encouraged.

The group 4 project allows students to appreciate the environmental, social and ethical implications of science and technology. It may also allow them to understand the limitations of scientific study, for example, the shortage of appropriate data and/or the lack of resources. The emphasis is on interdisciplinary cooperation and the processes involved in scientific investigation, rather than the products of such investigation.

The choice of scientific or technological topic is open but the project should clearly address aims 7, 8 and 10 of the group 4 subject guides.

Ideally, the project should involve students collaborating with those from other group 4 subjects at all stages. To this end, it is not necessary for the topic chosen to have clearly identifiable separate subject components. However, for logistical reasons some schools may prefer a separate subject "action" phase (see the following "Project stages" section).

## Project stages

The 10 hours allocated to the group 4 project, which are part of the teaching time set aside for IA, can be divided into three stages: planning, action and evaluation.

### Planning

This stage is crucial to the whole exercise and should last about two hours.

- The planning stage could consist of a single session, or two or three shorter ones.
- This stage must involve all group 4 students meeting to "brainstorm" and discuss the central topic, sharing ideas and information.
- The topic can be chosen by the students themselves or selected by the teachers.
- Where large numbers of students are involved, it may be advisable to have more than one mixed subject group.

**After selecting a topic or issue, the activities to be carried out must be clearly defined before moving from the planning stage to the action and evaluation stages.**

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A possible strategy is that students define specific tasks for themselves, either individually or as members of groups, and investigate various aspects of the chosen topic. At this stage, if the project is to be experimentally based, apparatus should be specified so that there is no delay in carrying out the action stage. Contact with other schools, if a joint venture has been agreed, is an important consideration at this time.

### Action

This stage should last around six hours and may be carried out over one or two weeks in normal scheduled class time. Alternatively, a whole day could be set aside if, for example, the project involves fieldwork.

- Students should investigate the topic in mixed subject groups or single subject groups.
- There should be collaboration during the action stage; findings of investigations should be shared with other students within the mixed/single subject group. During this stage, in any practically based activity, it is important to pay attention to safety, ethical and environmental considerations.

Note: Students studying two group 4 subjects are not required to do two separate action phases.

### Evaluation

The emphasis during this stage, for which two hours is probably necessary, is on students sharing their findings, both successes and failures, with other students. How this is achieved can be decided by the teachers, the students or jointly.

- One solution is to devote a morning, afternoon or evening to a symposium where all the students, as individuals or as groups, give brief presentations.
- Alternatively, the presentation could be more informal and take the form of a science fair where students circulate around displays summarizing the activities of each group.

The symposium or science fair could also be attended by parents, members of the school board and the press. This would be especially pertinent if some issue of local importance has been researched. Some of the findings might influence the way the school interacts with its environment or local community.

## Addressing aims 7 and 8

**Aim 7**—“develop and apply the students’ information and communication technology skills in the study of science”.

Aim 7 may be partly addressed at the planning stage by using electronic communication within and between schools. It may be that ICT (for example, data logging, spreadsheets, databases, and so on) will be used in the action phase and certainly in the presentation/evaluation stage (for example, use of digital images, presentation software, web sites, digital video, and so on).

**Aim 8**—“raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology”.

The choice of topic should enable one or more elements of aim 8 to be incorporated into the project.

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# Addressing the international dimension

There are also possibilities in the choice of topic to illustrate the international nature of the scientific endeavour and the increasing cooperation required to tackle global issues involving science and technology. An alternative way to bring an international dimension to the project is to collaborate with a school in another region.

# Types of project

While addressing aims 7, 8 and 10 the project must be based on science or its applications.

The project may have a hands-on practical action phase or one involving purely theoretical aspects. It could be undertaken in a wide range of ways.

- Designing and carrying out a laboratory investigation or fieldwork.
- Carrying out a comparative study (experimental or otherwise) in collaboration with another school.
- Collating, manipulating and analysing data from other sources, such as scientific journals, environmental organizations, science and technology industries and government reports.
- Designing and using a model or simulation.
- Contributing to a long-term project organized by the school.

# Logistical strategies

The logistical organization of the group 4 project is often a challenge to schools. The following models illustrate possible ways in which the project may be implemented.

Models A, B and C apply within a single school, and model D relates to a project involving collaboration between schools.

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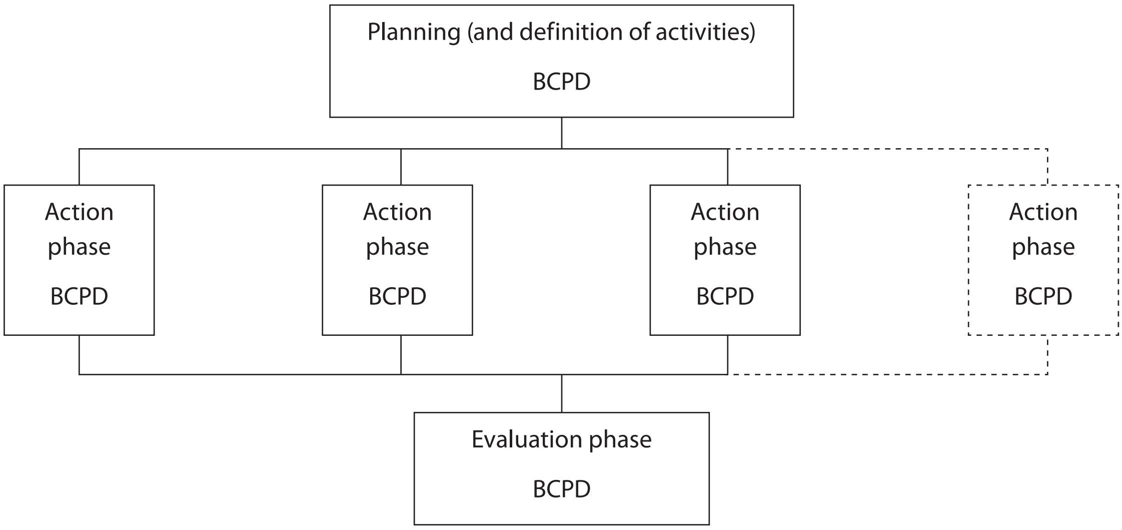
## Model A: mixed subject groups and one topic

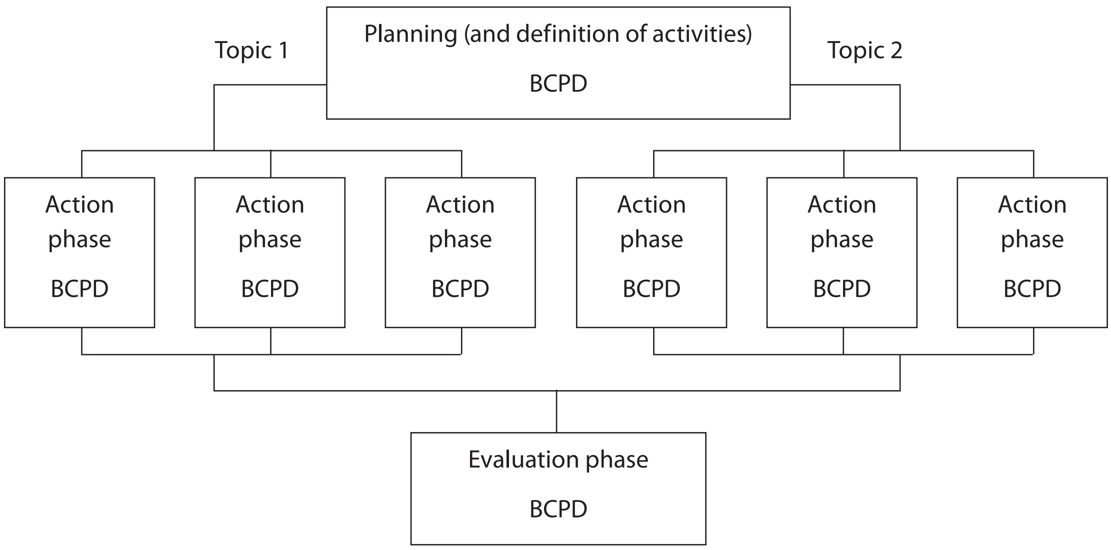
Schools may adopt mixed subject groups and choose one common topic. The number of groups will depend on the number of students. The dotted lines in the model show the addition of more groups as student numbers increase.

B—biology C—chemistry P—physics D—design technology




## Model B: mixed subject groups adopting more than one topic

Schools with large numbers of students may choose to do more than one topic.




## Model C: single subject groups

For schools opting for single subject groups with one or more topics in the action phase, simply replace the mixed subject groups in model A or B with single subject groups.

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### Model D: collaboration with another school

The collaborative model is open to any school. To this end, the IBO will provide an electronic collaboration board on the OCC where schools can post their project ideas and invite collaboration from another school. This could range from merely sharing evaluations for a common topic to a full-scale collaborative venture at all stages.

For schools with few diploma students or schools with certificate students, it is possible to work with non-Diploma Programme or non-group 4 students or undertake the project once every two years. However, these schools are encouraged to collaborate with another school. This strategy is also recommended for individual students who may not have participated in the project, for example, through illness or because they have transferred to a new school where the project has already taken place.

## Timing

The 10 hours that the IBO recommends be allocated to the project may be spread over a number of weeks. The distribution of these hours needs to be taken into account when selecting the optimum time to carry out the project. However, it is possible for a group to dedicate a period of time exclusively to project work if all/most other school work is suspended.

### Year 1

In the first year, students' experience and skills may be limited and it would be inadvisable to start the project too soon in the course. However, doing the project in the final part of the first year may have the advantage of reducing pressure on students later on. This strategy provides time for solving unexpected problems.

### Year 1–year 2

The planning stage could start, the topic could be decided upon, and provisional discussion in individual subjects could take place at the end of the first year. Students could then use the vacation time to think about how they are going to tackle the project and would be ready to start work early in the second year.

### Year 2

Delaying the start of the project until some point in the second year, particularly if left too late, increases pressure on students in many ways: the schedule for finishing the work is much tighter than for the other options; the illness of any student or unexpected problems will present extra difficulties. Nevertheless, this choice does mean students know one another and their teachers by this time, have probably become accustomed to working in a team and will be more experienced in the relevant fields than in the first year.

### Combined SL and HL

Where circumstances dictate that the project is only carried out every two years, HL beginners and more experienced SL students can be combined.

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# Selecting a topic

Students may choose the topic or propose possible topics, with the teacher then deciding which one is the most viable based on resources, staff availability, and so on. Alternatively, the teacher selects the topic or proposes several topics from which students make a choice.

## Student selection

Students are likely to display more enthusiasm and feel a greater sense of ownership for a topic that they have chosen themselves. A possible strategy for student selection of a topic, which also includes part of the planning stage, is outlined here. At this point, subject teachers may provide advice on the viability of proposed topics.

- Identify possible topics by using a questionnaire or a survey of students.
- Conduct an initial “brainstorming” session of potential topics or issues.
- Discuss, briefly, two or three topics that seem interesting.
- Select one topic by consensus.
- Students make a list of potential investigations that could be carried out. All students then discuss issues such as possible overlap and collaborative investigations.

# Assessment

The group 4 project is to be assessed for the personal skills criterion only and this will be the only place where this criterion is assessed. It is up to the school how this assessment takes place.

Note: The group 4 project is not to be used for the assessment of the other criteria.

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## Personal skills (for group 4 project assessment only)

This criterion addresses objective 4.

| Levels/marks | Aspect 1 | Aspect 2 | Aspect 3 |
|---|---|---|---|
| | Self-motivation and perseverance | Working within a team | Self-reflection |
| **Complete/2** | Approaches the project with self-motivation and follows it through to completion. | Collaborates and communicates in a group situation and integrates the views of others. | Shows a thorough awareness of their own strengths and weaknesses and gives thoughtful consideration to their learning experience. |
| **Partial/1** | Completes the project but sometimes lacks self-motivation. | Exchanges some views but requires guidance to collaborate with others. | Shows limited awareness of their own strengths and weaknesses and gives some consideration to their learning experience. |
| **Not at all/0** | Lacks perseverance and motivation. | Makes little or no attempt to collaborate in a group situation. | Shows no awareness of their own strengths and weaknesses and gives no consideration to their learning experience. |

The assessment can be assisted by the use of a student self-evaluation form, but the use of such a form is not a requirement.


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# Nature of the subject

Physics is the most fundamental of the experimental sciences, as it seeks to explain the universe itself, from the very smallest particles—quarks (perhaps $10^{-17}$ m in size), which may be truly fundamental—to the vast distances between galaxies ($10^{24}$ m).

Classical physics, built upon the great pillars of Newtonian mechanics, electromagnetism and thermodynamics, went a long way in deepening our understanding of the universe. From Newtonian mechanics came the idea of predictability in which the universe is deterministic and knowable. This led to Laplace's boast that by knowing the initial conditions—the position and velocity of every particle in the universe—he could, in principle, predict the future with absolute certainty. Maxwell's theory of electromagnetism described the behaviour of electric charge and unified light and electricity, while thermodynamics described the relation between heat and work and described how all natural processes increase disorder in the universe.

However, experimental discoveries dating from the end of the 19th century eventually led to the demise of the classical picture of the universe as being knowable and predictable. Newtonian mechanics failed when applied to the atom and has been superseded by quantum mechanics and general relativity. Maxwell's theory could not explain the interaction of radiation with matter and was replaced by quantum electrodynamics (QED). More recently, developments in chaos theory, in which it is now realized that small changes in the initial conditions of a system can lead to completely unpredictable outcomes, have led to a fundamental rethinking in thermodynamics.

While chaos theory shows that Laplace's boast is hollow, quantum mechanics and QED show that the initial conditions that Laplace required are impossible to establish. Nothing is certain and everything is decided by probability. But there is still much that is unknown and there will undoubtedly be further paradigm shifts as our understanding deepens.

Despite the exciting and extraordinary development of ideas throughout the history of physics, certain things have remained unchanged. Observations remain essential at the very core of physics, and this sometimes requires a leap of imagination to decide what to look for. Models are developed to try to understand the observations, and these themselves can become theories that attempt to explain the observations. Theories are not directly derived from the observations but need to be created. These acts of creation can sometimes compare to those in great art, literature and music, but differ in one aspect that is unique to science: the predictions of these theories or ideas must be tested by careful experimentation. Without these tests, a theory is useless. A general or concise statement about how nature behaves, if found to be experimentally valid over a wide range of observed phenomena, is called a law or a principle.

The scientific processes carried out by the most eminent scientists in the past are the same ones followed by working physicists today and, crucially, are also accessible to students in schools. Early in the development of science, physicists were both theoreticians and experimenters (natural philosophers). The body of scientific knowledge has grown in size and complexity, and the tools and skills of theoretical and experimental physicists have become so specialized, that it is difficult (if not impossible) to be highly proficient in both areas. While students should be aware of this, they should also know that the free and rapid interplay of theoretical ideas and experimental results in the public scientific literature maintains the crucial links between these fields.

At the school level both theory and experiments should be undertaken by all students. They should complement one another naturally, as they do in the wider scientific community. The Diploma Programme physics course allows students to develop traditional practical skills and techniques and to increase facility in the use of mathematics, which is the language of physics. It also allows students to develop interpersonal skills, and information and communication technology skills, which are essential in modern scientific endeavour and are important life-enhancing, transferable skills in their own right.

Alongside the growth in our understanding of the natural world, perhaps the more obvious and relevant result of physics to most of our students is our ability to change the world. This is the technological side of physics, in which physical principles have been applied to construct and alter the material world to suit our needs, and have had a profound influence on the daily lives of all human beings—for good or bad. This raises the issue of the impact of physics on society, the moral and ethical dilemmas, and the social, economic and environmental implications of the work of physicists. These concerns have become more prominent as our power over the environment has grown, particularly among young people, for whom the importance of the responsibility of physicists for their own actions is self-evident.

Physics is therefore, above all, a human activity, and students need to be aware of the context in which physicists work. Illuminating its historical development places the knowledge and the process of physics in a context of dynamic change, in contrast to the static context in which physics has sometimes been presented. This can give students insights into the human side of physics: the individuals; their personalities, times and social milieux; and their challenges, disappointments and triumphs.


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# Syllabus overview

The syllabus for the Diploma Programme physics course is divided into three parts: the core, the AHL material and the options. The *Physics data booklet* is an integral part of the syllabus and should be used in conjunction with the syllabus. Students should use the data booklet during the course, and they should be issued with clean copies for papers 1, 2 and 3 in the examination.

| | | Teaching hours |
|---|---|---|
| **Core** | | **80** |
| Topic 1: | Physics and physical measurement | 5 |
| Topic 2: | Mechanics | 17 |
| Topic 3: | Thermal physics | 7 |
| Topic 4: | Oscillations and waves | 10 |
| Topic 5: | Electric currents | 7 |
| Topic 6: | Fields and forces | 7 |
| Topic 7: | Atomic and nuclear physics | 9 |
| Topic 8: | Energy, power and climate change | 18 |
| **AHL** | | **55** |
| Topic 9: | Motion in fields | 8 |
| Topic 10: | Thermal physics | 6 |
| Topic 11: | Wave phenomena | 12 |
| Topic 12: | Electromagnetic induction | 6 |
| Topic 13: | Quantum physics and nuclear physics | 15 |
| Topic 14: | Digital technology | 8 |
| **Options** | | **15/22** |
| **Options SL** | | |
| Option A: | Sight and wave phenomena | 15 |
| Option B: | Quantum physics and nuclear physics | 15 |
| Option C: | Digital technology | 15 |
| Option D: | Relativity and particle physics | 15 |

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| | | Teaching hours |
|---|---|---|
| **Options SL and HL** | | |
| Option E: | Astrophysics | 15/22 |
| Option F: | Communications | 15/22 |
| Option G: | Electromagnetic waves | 15/22 |
| **Options HL** | | |
| Option H: | Relativity | 22 |
| Option I: | Medical physics | 22 |
| Option J: | Particle physics | 22 |

Students at SL are required to study any **two** options from A–G.
The duration of each option is 15 hours.

Students at HL are required to study any **two** options from E–J.
The duration of each option is 22 hours.

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# Syllabus outline

| | | Teaching hours |
|---|---|---|
| **Core** | | **80** |
| **Topic 1: Physics and physical measurement** | | **5** |
| 1.1 | The realm of physics | 1 |
| 1.2 | Measurement and uncertainties | 2 |
| 1.3 | Vectors and scalars | 2 |
| **Topic 2 : Mechanics** | | **17** |
| 2.1 | Kinematics | 6 |
| 2.2 | Forces and dynamics | 6 |
| 2.3 | Work, energy and power | 3 |
| 2.4 | Uniform circular motion | 2 |
| **Topic 3 : Thermal physics** | | **7** |
| 3.1 | Thermal concepts | 2 |
| 3.2 | Thermal properties of matter | 5 |
| **Topic 4: Oscillations and waves** | | **10** |
| 4.1 | Kinematics of simple harmonic motion (SHM) | 2 |
| 4.2 | Energy changes during simple harmonic motion (SHM) | 1 |
| 4.3 | Forced oscillations and resonance | 3 |
| 4.4 | Wave characteristics | 2 |
| 4.5 | Wave properties | 2 |
| **Topic 5: Electric currents** | | **7** |
| 5.1 | Electric potential difference, current and resistance | 4 |
| 5.2 | Electric circuits | 3 |
| **Topic 6: Fields and forces** | | **7** |
| 6.1 | Gravitational force and field | 2 |
| 6.2 | Electric force and field | 3 |
| 6.3 | Magnetic force and field | 2 |
| **Topic 7: Atomic and nuclear physics** | | **9** |
| 7.1 | The atom | 2 |
| 7.2 | Radioactive decay | 3 |
| 7.3 | Nuclear reactions, fission and fusion | 4 |

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| | | Teaching hours |
|---|---|---|
| **Topic 8: Energy, power and climate change** | | **18** |
| 8.1 | Energy degradation and power generation | 2 |
| 8.2 | World energy sources | 2 |
| 8.3 | Fossil fuel power production | 1 |
| 8.4 | Non-fossil fuel power production | 7 |
| 8.5 | Greenhouse effect | 3 |
| 8.6 | Global warming | 3 |
| **AHL** | | **55** |
| **Topic 9: Motion in fields** | | **8** |
| 9.1 | Projectile motion | 2 |
| 9.2 | Gravitational field, potential and energy | 2 |
| 9.3 | Electric field, potential and energy | 2 |
| 9.4 | Orbital motion | 2 |
| **Topic 10: Thermal physics** | | **6** |
| 10.1 | Thermodynamics | 2 |
| 10.2 | Processes | 3 |
| 10.3 | Second law of thermodynamics and entropy | 1 |
| **Topic 11: Wave phenomena** | | **12** |
| 11.1 | Standing (stationary) waves | 2 |
| 11.2 | Doppler effect | 2 |
| 11.3 | Diffraction | 1 |
| 11.4 | Resolution | 4 |
| 11.5 | Polarization | 3 |
| **Topic 12: Electromagnetic induction** | | **6** |
| 12.1 | Induced electromotive force (emf) | 3 |
| 12.2 | Alternating current | 2 |
| 12.3 | Transmission of electrical power | 1 |
| **Topic 13: Quantum physics and nuclear physics** | | **15** |
| 13.1 | Quantum physics | 10 |
| 13.2 | Nuclear physics | 5 |
| **Topic 14: Digital technology** | | **8** |
| 14.1 | Analogue and digital signals | 4 |
| 14.2 | Data capture; digital imaging using charge-coupled devices (CCDs) | 4 |


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| | | Teaching hours |
|---|---|---|
| **Options SL** | | **15** |

These options are available at SL only.

| | | |
|---|---|---|
| **Option A: Sight and wave phenomena** | | **15** |
| A1 | The eye and sight | 3 |
| A2 | Standing (stationary) waves | 2 |
| A3 | Doppler effect | 2 |
| A4 | Diffraction | 1 |
| A5 | Resolution | 4 |
| A6 | Polarization | 3 |
| **Option B: Quantum physics and nuclear physics** | | **15** |
| B1 | Quantum physics | 10 |
| B2 | Nuclear physics | 5 |
| **Option C: Digital technology** | | **15** |
| C1 | Analogue and digital signals | 4 |
| C2 | Data capture; digital imaging using charge-coupled devices (CCDs) | 4 |
| C3 | Electronics | 5 |
| C4 | The mobile phone system | 2 |
| **Option D: Relativity and particle physics** | | **15** |
| D1 | Introduction to relativity | 1 |
| D2 | Concepts and postulates of special relativity | 2 |
| D3 | Relativistic kinematics | 5 |
| D4 | Particles and interactions | 5 |
| D5 | Quarks | 2 |

## Options SL and HL — 15/22

SL students study the core of these options, and HL students study the whole option (that is, the core and the extension material).

| | | |
|---|---|---|
| **Option E: Astrophysics** | | **15/22** |
| **Core (SL and HL)** | | **15** |
| E1 | Introduction to the universe | 2 |
| E2 | Stellar radiation and stellar types | 4 |
| E3 | Stellar distances | 5 |
| E4 | Cosmology | 4 |
| **Extension (HL only)** | | **7** |
| E5 | Stellar processes and stellar evolution | 4 |
| E6 | Galaxies and the expanding universe | 3 |

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| | | Teaching hours |
|---|---|---|
| **Option F: Communications** | | **15/22** |
| **Core (SL and HL)** | | **15** |
| F1 | Radio communication | 5 |
| F2 | Digital signals | 4 |
| F3 | Optic fibre transmission | 3 |
| F4 | Channels of communication | 3 |
| **Extension (HL only)** | | **7** |
| F5 | Electronics | 5 |
| F6 | The mobile phone system | 2 |
| **Option G: Electromagnetic waves** | | **15/22** |
| **Core (SL and HL)** | | **15** |
| G1 | Nature of EM waves and light sources | 4 |
| G2 | Optical instruments | 6 |
| G3 | Two-source interference of waves | 3 |
| G4 | Diffraction grating | 2 |
| **Extension (HL only)** | | **7** |
| G5 | X-rays | 4 |
| G6 | Thin-film interference | 3 |

## Options HL — 22

These options are available at HL only.

| | | |
|---|---|---|
| **Option H: Relativity** | | **22** |
| H1 | Introduction to relativity | 1 |
| H2 | Concepts and postulates of special relativity | 2 |
| H3 | Relativistic kinematics | 5 |
| H4 | Some consequences of special relativity | 4 |
| H5 | Evidence to support special relativity | 3 |
| H6 | Relativistic momentum and energy | 2 |
| H7 | General relativity | 4 |
| H8 | Evidence to support general relativity | 1 |
| **Option I: Medical physics** | | **22** |
| I1 | The ear and hearing | 6 |
| I2 | Medical imaging | 10 |
| I3 | Radiation in medicine | 6 |
| **Option J: Particle physics** | | **22** |
| J1 | Particles and interactions | 5 |
| J2 | Particle accelerators and detectors | 6 |
| J3 | Quarks | 2 |
| J4 | Leptons and the standard model | 2 |
| J5 | Experimental evidence for the quark and standard models | 5 |
| J6 | Cosmology and strings | 2 |


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# Syllabus details—Core

## Topic 1: Physics and physical measurement (5 hours)

### 1.1 The realm of physics

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Range of magnitudes of quantities in our universe** | | | |
| 1.1.1 | State and compare quantities to the nearest order of magnitude. | 3 | |
| 1.1.2 | State the ranges of magnitude of distances, masses and times that occur in the universe, from smallest to greatest. | 1 | Distances: from $10^{-15}$ m to $10^{+25}$ m (sub-nuclear particles to extent of the visible universe).<br>Masses: from $10^{-30}$ kg to $10^{+50}$ kg (electron to mass of the universe).<br>Times: from $10^{-23}$ s to $10^{+18}$ s (passage of light across a nucleus to the age of the universe).<br>**Aim 7:** There are some excellent simulations to illustrate this.<br>**TOK:** This is a very stimulating area for a discussion of ways of knowing. |
| 1.1.3 | State ratios of quantities as differences of orders of magnitude. | 1 | For example, the ratio of the diameter of the hydrogen atom to its nucleus is about $10^5$, or a difference of five orders of magnitude. |
| 1.1.4 | Estimate approximate values of everyday quantities to one or two significant figures and/or to the nearest order of magnitude. | 2 | |

### 1.2 Measurement and uncertainties

**2 hours**

**TOK:** Data and its limitations is a fruitful area for discussion.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The SI system of fundamental and derived units** | | | |
| 1.2.1 | State the fundamental units in the SI system. | 1 | Students need to know the following: kilogram, metre, second, ampere, mole and kelvin. |
| 1.2.2 | Distinguish between fundamental and derived units and give examples of derived units. | 2 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 1.2.3 | Convert between different units of quantities. | 2 | For example, J and kW h, J and eV, year and second, and between other systems and SI. |
| 1.2.4 | State units in the accepted SI format. | 1 | Students should use m $s^{-2}$ not m/$s^2$ and m $s^{-1}$ not m/s. |
| 1.2.5 | State values in scientific notation and in multiples of units with appropriate prefixes. | 1 | For example, use nanoseconds or gigajoules. |
| **Uncertainty and error in measurement** | | | |
| 1.2.6 | Describe and give examples of random and systematic errors. | 2 | |
| 1.2.7 | Distinguish between precision and accuracy. | 2 | A measurement may have great precision yet may be inaccurate (for example, if the instrument has a zero offset error). |
| 1.2.8 | Explain how the effects of random errors may be reduced. | 3 | Students should be aware that systematic errors are not reduced by repeating readings. |
| 1.2.9 | Calculate quantities and results of calculations to the appropriate number of significant figures. | 2 | The number of significant figures should reflect the precision of the value or of the input data to a calculation. Only a simple rule is required: for multiplication and division, the number of significant digits in a result should not exceed that of the least precise value upon which it depends.<br>The number of significant figures in any answer should reflect the number of significant figures in the given data. |
| **Uncertainties in calculated results** | | | |
| 1.2.10 | State uncertainties as absolute, fractional and percentage uncertainties. | 1 | |
| 1.2.11 | Determine the uncertainties in results. | 3 | A simple approximate method rather than root mean squared calculations is sufficient to determine maximum uncertainties. For functions such as addition and subtraction, absolute uncertainties may be added. For multiplication, division and powers, percentage uncertainties may be added. For other functions (for example, trigonometric functions), the mean, highest and lowest possible answers may be calculated to obtain the uncertainty range. If one uncertainty is much larger than others, the approximate uncertainty in the calculated result may be taken as due to that quantity alone. |
| **Uncertainties in graphs**<br>**Aim 7:** This is an opportunity to show how spreadsheets are commonly used to calculate and draw error bars on graphs. | | | |
| 1.2.12 | Identify uncertainties as error bars in graphs. | 2 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 1.2.13 | State random uncertainty as an uncertainty range (±) and represent it graphically as an "error bar". | 1 | Error bars need be considered only when the uncertainty in one or both of the plotted quantities is significant.<br>Error bars will not be expected for trigonometric or logarithmic functions. |
| 1.2.14 | Determine the uncertainties in the gradient and intercepts of a straight-line graph. | 3 | Only a simple approach is needed. To determine the uncertainty in the gradient and intercept, error bars need only be added to the first and the last data points. |

## 1.3 Vectors and scalars

**2 hours**

This may be taught as a stand-alone topic or can be introduced when vectors are encountered in other topics such as 2.2, forces and dynamics, and 6.2, electric force and field.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 1.3.1 | Distinguish between vector and scalar quantities, and give examples of each. | 2 | A vector is represented in print by a bold italicized symbol, for example, ***F***. |
| 1.3.2 | Determine the sum or difference of two vectors by a graphical method. | 3 | Multiplication and division of vectors by scalars is also required. |
| 1.3.3 | Resolve vectors into perpendicular components along chosen axes. | 2 | For example, resolving parallel and perpendicular to an inclined plane. |

# Topic 2: Mechanics (17 hours)

**Aim 7:** This topic is a fruitful one for using spreadsheets and data logging in practical work as well as computer simulations in teaching various concepts.

## 2.1 Kinematics

**6 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 2.1.1 | Define *displacement*, *velocity*, *speed* and *acceleration*. | 1 | Quantities should be identified as scalar or vector quantities. See sub-topic 1.3. |
| 2.1.2 | Explain the difference between instantaneous and average values of speed, velocity and acceleration. | 3 | |
| 2.1.3 | Outline the conditions under which the equations for uniformly accelerated motion may be applied. | 2 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 2.1.4 | Identify the acceleration of a body falling in a vacuum near the Earth's surface with the acceleration *g* of free fall. | 2 | |
| 2.1.5 | Solve problems involving the equations of uniformly accelerated motion. | 3 | |
| 2.1.6 | Describe the effects of air resistance on falling objects. | 2 | Only qualitative descriptions are expected. Students should understand what is meant by terminal speed. |
| 2.1.7 | Draw and analyse distance–time graphs, displacement–time graphs, velocity–time graphs and acceleration–time graphs. | 3 | Students should be able to sketch and label these graphs for various situations. They should also be able to write descriptions of the motions represented by such graphs. |
| 2.1.8 | Calculate and interpret the gradients of displacement–time graphs and velocity–time graphs, and the areas under velocity–time graphs and acceleration–time graphs. | 2 | |
| 2.1.9 | Determine relative velocity in one and in two dimensions. | 3 | |

## 2.2 Forces and dynamics

**6 hours**

**TOK:** The development of the laws of motion raises interesting issues relating to correlation and cause and scientific theories.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 2.2.1 | Calculate the weight of a body using the expression $W = mg$. | 2 | |
| 2.2.2 | Identify the forces acting on an object and draw free-body diagrams representing the forces acting. | 2 | Each force should be labelled by name or given a commonly accepted symbol. Vectors should have lengths approximately proportional to their magnitudes. See sub-topic 1.3. |
| 2.2.3 | Determine the resultant force in different situations. | 3 | |
| 2.2.4 | State Newton's first law of motion. | 1 | |
| 2.2.5 | Describe examples of Newton's first law. | 2 | |
| 2.2.6 | State the condition for translational equilibrium. | 1 | |
| 2.2.7 | Solve problems involving translational equilibrium. | 3 | |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 2.2.8 | State Newton's second law of motion. | 1 | Students should be familiar with the law expressed as: $F = ma$ and $F = \frac{\Delta p}{\Delta t}$. |
| 2.2.9 | Solve problems involving Newton's second law. | 3 | |
| 2.2.10 | Define *linear momentum* and *impulse*. | 1 | |
| 2.2.11 | Determine the impulse due to a time-varying force by interpreting a force–time graph. | 3 | |
| 2.2.12 | State the law of conservation of linear momentum. | 1 | |
| 2.2.13 | Solve problems involving momentum and impulse. | 3 | |
| 2.2.14 | State Newton's third law of motion. | 1 | |
| 2.2.15 | Discuss examples of Newton's third law. | 3 | Students should understand that when two bodies A and B interact, the force that A exerts on B is equal and opposite to the force that B exerts on A. |

## 2.3 Work, energy and power

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 2.3.1 | Outline what is meant by work. | 2 | Students should be familiar with situations where the displacement is not in the same direction as the force. |
| 2.3.2 | Determine the work done by a non-constant force by interpreting a force–displacement graph. | 3 | A typical example would be calculating the work done in extending a spring. See 2.3.7. |
| 2.3.3 | Solve problems involving the work done by a force. | 3 | |
| 2.3.4 | Outline what is meant by kinetic energy. | 2 | |
| 2.3.5 | Outline what is meant by change in gravitational potential energy. | 2 | |
| 2.3.6 | State the principle of conservation of energy. | 1 | |
| 2.3.7 | List different forms of energy and describe examples of the transformation of energy from one form to another. | 2 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 2.3.8 | Distinguish between elastic and inelastic collisions. | 2 | Students should be familiar with elastic and inelastic collisions and explosions. Knowledge of the coefficient of restitution is not required. |
| 2.3.9 | Define *power*. | 1 | |
| 2.3.10 | Define and apply the concept of *efficiency*. | 2 | |
| 2.3.11 | Solve problems involving momentum, work, energy and power. | 3 | |

## 2.4 Uniform circular motion

**2 hours**

This topic links with sub-topics 6.3 and 9.4.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 2.4.1 | Draw a vector diagram to illustrate that the acceleration of a particle moving with constant speed in a circle is directed towards the centre of the circle. | 1 | |
| 2.4.2 | Apply the expression for centripetal acceleration. | 2 | |
| 2.4.3 | Identify the force producing circular motion in various situations. | 2 | Examples include gravitational force acting on the Moon and friction acting sideways on the tyres of a car turning a corner. |
| 2.4.4 | Solve problems involving circular motion. | 3 | Problems on banked motion (aircraft and vehicles going round banked tracks) will not be included. |

# Topic 3: Thermal physics (7 hours)

## 3.1 Thermal concepts

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 3.1.1 | State that temperature determines the direction of thermal energy transfer between two objects. | 1 | Students should be familiar with the concept of thermal equilibrium. |
| 3.1.2 | State the relation between the Kelvin and Celsius scales of temperature. | 1 | $T/\text{K} = t/°\text{C} + 273$ is sufficient. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 3.1.3 | State that the internal energy of a substance is the total potential energy and random kinetic energy of the molecules of the substance. | 1 | Students should know that the kinetic energy of the molecules arises from their random/translational/rotational motion and that the potential energy of the molecules arises from the forces between the molecules. |
| 3.1.4 | Explain and distinguish between the macroscopic concepts of temperature, internal energy and thermal energy (heat). | 3 | Students should understand that the term thermal energy refers to the non-mechanical transfer of energy between a system and its surroundings.<br>In this respect it is just as incorrect to refer to the "thermal energy in a body" as it would be to refer to the "work in a body". |
| 3.1.5 | Define the *mole* and *molar mass*. | 1 | |
| 3.1.6 | Define the *Avogadro constant*. | 1 | |

## 3.2 Thermal properties of matter

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Specific heat capacity, phase changes and latent heat** | | | |
| 3.2.1 | Define *specific heat capacity* and *thermal capacity*. | 1 | |
| 3.2.2 | Solve problems involving specific heat capacities and thermal capacities. | 3 | |
| 3.2.3 | Explain the physical differences between the solid, liquid and gaseous phases in terms of molecular structure and particle motion. | 3 | Only a simple model is required. |
| 3.2.4 | Describe and explain the process of phase changes in terms of molecular behaviour. | 3 | Students should be familiar with the terms melting, freezing, evaporating, boiling and condensing, and should be able to describe each in terms of the changes in molecular potential and random kinetic energies of molecules. |
| 3.2.5 | Explain in terms of molecular behaviour why temperature does not change during a phase change. | 3 | |
| 3.2.6 | Distinguish between evaporation and boiling. | 2 | |
| 3.2.7 | Define *specific latent heat*. | 1 | |
| 3.2.8 | Solve problems involving specific latent heats. | 3 | Problems may include specific heat calculations. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Kinetic model of an ideal gas**<br>**Aim 7:** There are many computer simulations of the behaviour of gases.<br>**TOK:** The use of modelling in science may be introduced here. | | | |
| 3.2.9 | Define *pressure*. | 1 | |
| 3.2.10 | State the assumptions of the kinetic model of an ideal gas. | 1 | |
| 3.2.11 | State that temperature is a measure of the average random kinetic energy of the molecules of an ideal gas. | 1 | |
| 3.2.12 | Explain the macroscopic behaviour of an ideal gas in terms of a molecular model. | 3 | Only qualitative explanations are required. Students should, for example, be able to explain how a change in volume results in a change in the frequency of particle collisions with the container and how this relates to a change in pressure and/or temperature. |

# Topic 4: Oscillations and waves (10 hours)

## 4.1 Kinematics of simple harmonic motion (SHM)

**2 hours**

**Aim 7:** Many computer simulations of SHM are available.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 4.1.1 | Describe examples of oscillations. | 2 | |
| 4.1.2 | Define the terms *displacement*, *amplitude*, *frequency*, *period* and *phase difference*. | 1 | The connection between frequency and period should be known. |
| 4.1.3 | Define *simple harmonic motion* (*SHM*) and state the defining equation as $a = -\omega^2 x$. | 1 | Students are expected to understand the significance of the negative sign in the equation and to recall the connection between $\omega$ and $T$. |
| 4.1.4 | Solve problems using the defining equation for SHM. | 3 | |
| 4.1.5 | Apply the equations $v = v_0 \sin \omega t$, $v = v_0 \cos \omega t$, $v = \pm \omega \sqrt{\left(x_0^2 - x^2\right)}$, $x = x_0 \cos \omega t$ and $x = x_0 \sin \omega t$ as solutions to the defining equation for SHM. | 2 | |
| 4.1.6 | Solve problems, both graphically and by calculation, for acceleration, velocity and displacement during SHM. | 3 | |

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## 4.2 Energy changes during simple harmonic motion (SHM)

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 4.2.1 | Describe the interchange between kinetic energy and potential energy during SHM. | 2 | |
| 4.2.2 | Apply the expressions $E_K = \frac{1}{2}m\omega^2\left(x_0{}^2 - x^2\right)$ for the kinetic energy of a particle undergoing SHM, $E_T = \frac{1}{2}m\omega^2 x_0{}^2$ for the total energy and $E_P = \frac{1}{2}m\omega^2 x^2$ for the potential energy. | 2 | |
| 4.2.3 | Solve problems, both graphically and by calculation, involving energy changes during SHM. | 3 | |

## 4.3 Forced oscillations and resonance

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 4.3.1 | State what is meant by damping. | 1 | It is sufficient for students to know that damping involves a force that is always in the opposite direction to the direction of motion of the oscillating particle and that the force is a dissipative force. |
| 4.3.2 | Describe examples of damped oscillations. | 2 | Reference should be made to the degree of damping and the importance of critical damping. A detailed account of degrees of damping is not required. |
| 4.3.3 | State what is meant by natural frequency of vibration and forced oscillations. | 1 | |
| 4.3.4 | Describe graphically the variation with forced frequency of the amplitude of vibration of an object close to its natural frequency of vibration. | 2 | Students should be able to describe qualitatively factors that affect the frequency response and sharpness of the curve. |
| 4.3.5 | State what is meant by resonance. | 1 | |
| 4.3.6 | Describe examples of resonance where the effect is useful and where it should be avoided. | 2 | Examples may include quartz oscillators, microwave generators and vibrations in machinery. |

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# 4.4 Wave characteristics

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 4.4.1 | Describe a wave pulse and a continuous progressive (travelling) wave. | 2 | Students should be able to distinguish between oscillations and wave motion, and appreciate that, in many examples, the oscillations of the particles are simple harmonic. |
| 4.4.2 | State that progressive (travelling) waves transfer energy. | 1 | Students should understand that there is no net motion of the medium through which the wave travels. |
| 4.4.3 | Describe and give examples of transverse and of longitudinal waves. | 2 | Students should describe the waves in terms of the direction of oscillation of particles in the wave relative to the direction of transfer of energy by the wave. Students should know that sound waves are longitudinal, that light waves are transverse and that transverse waves cannot be propagated in gases. |
| 4.4.4 | Describe waves in two dimensions, including the concepts of wavefronts and of rays. | 2 | |
| 4.4.5 | Describe the terms crest, trough, compression and rarefaction. | 2 | |
| 4.4.6 | Define the terms *displacement*, *amplitude*, *frequency*, *period*, *wavelength*, *wave speed* and *intensity*. | 1 | Students should know that intensity $\propto$ amplitude$^2$. |
| 4.4.7 | Draw and explain displacement–time graphs and displacement–position graphs for transverse and for longitudinal waves. | 3 | |
| 4.4.8 | Derive and apply the relationship between wave speed, wavelength and frequency. | 3 | |
| 4.4.9 | State that all electromagnetic waves travel with the same speed in free space, and recall the orders of magnitude of the wavelengths of the principal radiations in the electromagnetic spectrum. | 1 | |

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## 4.5 Wave properties

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 4.5.1 | Describe the reflection and transmission of waves at a boundary between two media. | 2 | This should include the sketching of incident, reflected and transmitted waves. |
| 4.5.2 | State and apply Snell's law. | 2 | Students should be able to define refractive index in terms of the ratio of the speeds of the wave in the two media and also in terms of the angles of incidence and refraction. |
| 4.5.3 | Explain and discuss qualitatively the diffraction of waves at apertures and obstacles. | 3 | The effect of wavelength compared to aperture or obstacle dimensions should be discussed. |
| 4.5.4 | Describe examples of diffraction. | 2 | |
| 4.5.5 | State the principle of superposition and explain what is meant by constructive interference and by destructive interference. | 3 | |
| 4.5.6 | State and apply the conditions for constructive and for destructive interference in terms of path difference and phase difference. | 2 | |
| 4.5.7 | Apply the principle of superposition to determine the resultant of two waves. | 2 | |

# Topic 5: Electric currents (7 hours)

## 5.1 Electric potential difference, current and resistance

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Electric potential difference** | | | |
| 5.1.1 | Define *electric potential difference*. | 1 | |
| 5.1.2 | Determine the change in potential energy when a charge moves between two points at different potentials. | 3 | |
| 5.1.3 | Define the *electronvolt*. | 1 | |
| 5.1.4 | Solve problems involving electric potential difference. | 3 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Electric current and resistance** | | | |
| 5.1.5 | Define *electric current*. | 1 | It is sufficient for students to know that current is defined in terms of the force per unit length between parallel current-carrying conductors. |
| 5.1.6 | Define *resistance*. | 1 | Students should be aware that $R = V/I$ is a general definition of resistance. It is not a statement of Ohm's law. Students should understand what is meant by resistor. |
| 5.1.7 | Apply the equation for resistance in the form $R = \frac{\rho L}{A}$ where $\rho$ is the resistivity of the material of the resistor. | 2 | |
| 5.1.8 | State Ohm's law. | 1 | |
| 5.1.9 | Compare ohmic and non-ohmic behaviour. | 3 | For example, students should be able to draw the $I$–$V$ characteristics of an ohmic resistor and a filament lamp. |
| 5.1.10 | Derive and apply expressions for electrical power dissipation in resistors. | 3 | |
| 5.1.11 | Solve problems involving potential difference, current and resistance. | 3 | |

## 5.2 Electric circuits

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 5.2.1 | Define *electromotive force* (*emf*). | 1 | |
| 5.2.2 | Describe the concept of internal resistance. | 2 | |
| 5.2.3 | Apply the equations for resistors in series and in parallel. | 2 | This includes combinations of resistors and also complete circuits involving internal resistance. |
| 5.2.4 | Draw circuit diagrams. | 1 | Students should be able to recognize and use the accepted circuit symbols. |
| 5.2.5 | Describe the use of ideal ammeters and ideal voltmeters. | 2 | |
| 5.2.6 | Describe a potential divider. | 2 | |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 5.2.7 | Explain the use of sensors in potential divider circuits. | 3 | Sensors should include light-dependent resistors (LDRs), negative temperature coefficient (NTC) thermistors and strain gauges. |
| 5.2.8 | Solve problems involving electric circuits. | 3 | Students should appreciate that many circuit problems may be solved by regarding the circuit as a potential divider. Students should be aware that ammeters and voltmeters have their own resistance. |

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# Topic 6: Fields and forces (7 hours)

In this topic, the similarities and differences between the fields should be brought to the attention of students.

**TOK:** The concept of fields in science is well worth exploring.

## 6.1 Gravitational force and field

2 hours

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 6.1.1 | State Newton's universal law of gravitation. | 1 | Students should be aware that the masses in the force law are point masses. The force between two spherical masses whose separation is large compared to their radii is the same as if the two spheres were point masses with their masses concentrated at the centres of the spheres. |
| 6.1.2 | Define *gravitational field strength*. | 1 | |
| 6.1.3 | Determine the gravitational field due to one or more point masses. | 3 | |

## 6.2 Electric force and field

3 hours

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 6.2.1 | State that there are two types of electric charge. | 1 | |
| 6.2.2 | State and apply the law of conservation of charge. | 2 | |
| 6.2.3 | Describe and explain the difference in the electrical properties of conductors and insulators. | 3 | |
| 6.2.4 | State Coulomb's law. | 1 | Students should be aware that the charges in the force law are point charges. |
| 6.2.5 | Define *electric field strength*. | 1 | Students should understand the concept of a test charge. |
| 6.2.6 | Determine the electric field strength due to one or more point charges. | 3 | |


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| | Assessment statement | Obj | Teacher's notes | | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|---|---|---|---|
| 6.1.4 | Derive an expression for gravitational field strength at the surface of a planet, assuming that all its mass is concentrated at its centre. | 3 | | | | | |
| | | | | 6.2.7 | Draw the electric field patterns for different charge configurations. | 1 | These include the fields due to the following charge configurations: a point charge, a charged sphere, two point charges, and oppositely charged parallel plates. The latter includes the edge effect. Students should understand what is meant by radial field. |
| 6.1.5 | Solve problems involving gravitational forces and fields. | 3 | | 6.2.8 | Solve problems involving electric charges, forces and fields. | 3 | |

## 6.3 Magnetic force and field

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 6.3.1 | State that moving charges give rise to magnetic fields. | 1 | |
| 6.3.2 | Draw magnetic field patterns due to currents. | 1 | These include the fields due to currents in a straight wire, a flat circular coil and a solenoid. |
| 6.3.3 | Determine the direction of the force on a current-carrying conductor in a magnetic field. | 3 | Different rules may be used to determine the force direction. Knowledge of any particular rule is not required. |
| 6.3.4 | Determine the direction of the force on a charge moving in a magnetic field. | 3 | |
| 6.3.5 | Define the *magnitude* and *direction* of a magnetic field. | 1 | |
| 6.3.6 | Solve problems involving magnetic forces, fields and currents. | 3 | |

# Topic 7: Atomic and nuclear physics (9 hours)

**Aim 7:** There are opportunities throughout this topic to look at databases, use spreadsheets, explore simulations and perform data-logging experiments.

## 7.1 The atom

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Atomic structure** | | | |
| 7.1.1 | Describe a model of the atom that features a small nucleus surrounded by electrons. | 2 | Students should be able to describe a simple model involving electrons kept in orbit around the nucleus as a result of the electrostatic attraction between the electrons and the nucleus. |
| 7.1.2 | Outline the evidence that supports a nuclear model of the atom. | 2 | A qualitative description of the Geiger–Marsden experiment and an interpretation of the results are all that is required. |
| 7.1.3 | Outline one limitation of the simple model of the nuclear atom. | 2 | |
| 7.1.4 | Outline evidence for the existence of atomic energy levels. | 2 | Students should be familiar with emission and absorption spectra, but the details of atomic models are not required.<br>Students should understand that light is not a continuous wave but is emitted as "packets" or "photons" of energy, each of energy *hf*. |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Nuclear structure** | | | |
| 7.1.5 | Explain the terms nuclide, isotope and nucleon. | 3 | |
| 7.1.6 | Define *nucleon number A*, *proton number Z* and *neutron number N*. | 1 | |
| 7.1.7 | Describe the interactions in a nucleus. | 2 | Students need only know about the Coulomb interaction between protons and the strong, short-range nuclear interaction between nucleons. |

## 7.2 Radioactive decay

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Radioactivity** | | | |
| 7.2.1 | Describe the phenomenon of natural radioactive decay. | 2 | The inclusion of the antineutrino in $\beta^-$ decay is required. |
| 7.2.2 | Describe the properties of alpha (α) and beta (β) particles and gamma (γ) radiation. | 2 | |
| 7.2.3 | Describe the ionizing properties of alpha (α) and beta (β) particles and gamma (γ) radiation. | 2 | |
| 7.2.4 | Outline the biological effects of ionizing radiation. | 2 | Students should be familiar with the direct and indirect effects of radiation on structures within cells. A simple account of short-term and long-term effects of radiation on the body is required.<br>**Aim 8:** There are moral, social and environmental aspects to consider here.<br>**TOK:** Correlation and cause, and risk assessment, can also be looked at. |
| 7.2.5 | Explain why some nuclei are stable while others are unstable. | 3 | An explanation in terms of relative numbers of protons and neutrons and the forces involved is all that is required. |
| **Half-life** | | | |
| 7.2.6 | State that radioactive decay is a random and spontaneous process and that the rate of decay decreases exponentially with time. | 1 | Exponential decay need not be treated analytically. It is sufficient to know that any quantity that reduces to half its initial value in a constant time decays exponentially. The nature of the decay is independent of the initial amount. |
| 7.2.7 | Define the term *radioactive half-life*. | 1 | |
| 7.2.8 | Determine the half-life of a nuclide from a decay curve. | 3 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 7.2.9 | Solve radioactive decay problems involving integral numbers of half-lives. | 3 | |

## 7.3 Nuclear reactions, fission and fusion

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Nuclear reactions** | | | |
| 7.3.1 | Describe and give an example of an artificial (induced) transmutation. | 2 | |
| 7.3.2 | Construct and complete nuclear equations. | 3 | |
| 7.3.3 | Define the term *unified atomic mass unit*. | 1 | Students must be familiar with the units MeV $c^{-2}$ and GeV $c^{-2}$ for mass. |
| 7.3.4 | Apply the Einstein mass–energy equivalence relationship. | 2 | |
| 7.3.5 | Define the concepts of *mass defect*, *binding energy* and *binding energy per nucleon*. | 1 | |
| 7.3.6 | Draw and annotate a graph showing the variation with nucleon number of the binding energy per nucleon. | 2 | Students should be familiar with binding energies plotted as positive quantities. |
| 7.3.7 | Solve problems involving mass defect and binding energy. | 3 | |
| **Fission and fusion** | | | |
| 7.3.8 | Describe the processes of nuclear fission and nuclear fusion. | 2 | |
| 7.3.9 | Apply the graph in 7.3.6 to account for the energy release in the processes of fission and fusion. | 2 | |
| 7.3.10 | State that nuclear fusion is the main source of the Sun's energy. | 1 | |
| 7.3.11 | Solve problems involving fission and fusion reactions. | 3 | |


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# Topic 8: Energy, power and climate change (18 hours)

Aim 8 and the international dimension feature strongly in all the sub-topics.

## 8.1 Energy degradation and power generation

**2 hours**

**Aim 7:** Computer simulations of Sankey diagrams feature here.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 8.1.1 | State that thermal energy may be completely converted to work in a single process, but that continuous conversion of this energy into work requires a cyclical process and the transfer of some energy from the system. | 1 | |
| 8.1.2 | Explain what is meant by degraded energy. | 3 | Students should understand that, in any process that involves energy transformations, the energy that is transferred to the surroundings (thermal energy) is no longer available to perform useful work. |
| 8.1.3 | Construct and analyse energy flow diagrams (Sankey diagrams) and identify where the energy is degraded. | 3 | It is expected that students will be able to construct flow diagrams for various systems including those described in sub-topics 8.3 and 8.4. |
| 8.1.4 | Outline the principal mechanisms involved in the production of electrical power. | 2 | Students should know that electrical energy may be produced by rotating coils in a magnetic field. In sub-topics 8.2 and 8.3 students look in more detail at energy sources used to provide the energy to rotate the coils. |

## 8.2 World energy sources

**2 hours**

**Aim 7:** Databases of energy statistics on a global and national scale can be explored here. Moral, environmental and economic aspects may be considered.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 8.2.1 | Identify different world energy sources. | 2 | Students should be able to recognize those sources associated with $CO_2$ emission.<br>Students should also appreciate that, in most instances, the Sun is the prime energy source for world energy. |
| 8.2.2 | Outline and distinguish between renewable and non-renewable energy sources. | 2 | |
| 8.2.3 | Define the *energy density* of a fuel. | 1 | Energy density is measured in $J\ kg^{-1}$. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 8.2.4 | Discuss how choice of fuel is influenced by its energy density. | 3 | The values of energy density of different fuels will be provided. |
| 8.2.5 | State the relative proportions of world use of the different energy sources that are available. | 1 | Only approximate values are needed. |
| 8.2.6 | Discuss the relative advantages and disadvantages of various energy sources. | 3 | The discussion applies to all the sources identified in sub-topics 8.2, 8.3 and 8.4. |

## 8.3 Fossil fuel power production

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 8.3.1 | Outline the historical and geographical reasons for the widespread use of fossil fuels. | 2 | Students should appreciate that industrialization led to a higher rate of energy usage, leading to industry being developed near to large deposits of fossil fuels. |
| 8.3.2 | Discuss the energy density of fossil fuels with respect to the demands of power stations. | 3 | Students should be able to estimate the rate of fuel consumption by power stations. |
| 8.3.3 | Discuss the relative advantages and disadvantages associated with the transportation and storage of fossil fuels. | 3 | |
| 8.3.4 | State the overall efficiency of power stations fuelled by different fossil fuels. | 1 | Only approximate values are required. |
| 8.3.5 | Describe the environmental problems associated with the recovery of fossil fuels and their use in power stations. | 2 | |

## 8.4 Non-fossil fuel power production

**7 hours**

**Aim 7:** Computer simulations may be shown modelling nuclear power stations and nuclear processes in general.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Nuclear power** | | | |
| 8.4.1 | Describe how neutrons produced in a fission reaction may be used to initiate further fission reactions (chain reaction). | 2 | Students should know that only low-energy neutrons ($\approx$ 1 eV) favour nuclear fission. They should also know about critical mass. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 8.4.2 | Distinguish between controlled nuclear fission (power production) and uncontrolled nuclear fission (nuclear weapons). | 2 | Students should be aware of the moral and ethical issues associated with nuclear weapons. |
| 8.4.3 | Describe what is meant by fuel enrichment. | 2 | |
| 8.4.4 | Describe the main energy transformations that take place in a nuclear power station. | 2 | |
| 8.4.5 | Discuss the role of the moderator and the control rods in the production of controlled fission in a thermal fission reactor. | 3 | |
| 8.4.6 | Discuss the role of the heat exchanger in a fission reactor. | 3 | |
| 8.4.7 | Describe how neutron capture by a nucleus of uranium-238 ($^{238}U$) results in the production of a nucleus of plutonium-239 ($^{239}Pu$). | 2 | |
| 8.4.8 | Describe the importance of plutonium-239 ($^{239}Pu$) as a nuclear fuel. | 2 | It is sufficient for students to know that plutonium-239 ($^{239}Pu$) is used as a fuel in other types of reactors. |
| 8.4.9 | Discuss safety issues and risks associated with the production of nuclear power. | 3 | Such issues involve:<br>• the possibility of thermal meltdown and how it might arise<br>• problems associated with nuclear waste<br>• problems associated with the mining of uranium<br>• the possibility that a nuclear power programme may be used as a means to produce nuclear weapons. |
| 8.4.10 | Outline the problems associated with producing nuclear power using nuclear fusion. | 2 | It is sufficient that students appreciate the problem of maintaining and confining a high-temperature, high-density plasma. |
| 8.4.11 | Solve problems on the production of nuclear power. | 3 | |
| **Solar power** | | | |
| 8.4.12 | Distinguish between a photovoltaic cell and a solar heating panel. | 2 | Students should be able to describe the energy transfers involved and outline appropriate uses of these devices. |
| 8.4.13 | Outline reasons for seasonal and regional variations in the solar power incident per unit area of the Earth's surface. | 2 | |
| 8.4.14 | Solve problems involving specific applications of photovoltaic cells and solar heating panels. | 3 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Hydroelectric power** | | | |
| 8.4.15 | Distinguish between different hydroelectric schemes. | 2 | Students should know that the different schemes are based on:<br>• water storage in lakes<br>• tidal water storage<br>• pump storage. |
| 8.4.16 | Describe the main energy transformations that take place in hydroelectric schemes. | 2 | |
| 8.4.17 | Solve problems involving hydroelectric schemes. | 3 | |
| **Wind power** | | | |
| 8.4.18 | Outline the basic features of a wind generator. | 2 | A conventional horizontal-axis machine is sufficient. |
| 8.4.19 | Determine the power that may be delivered by a wind generator, assuming that the wind kinetic energy is completely converted into mechanical kinetic energy, and explain why this is impossible. | 3 | |
| 8.4.20 | Solve problems involving wind power. | 3 | |
| **Wave power** | | | |
| 8.4.21 | Describe the principle of operation of an oscillating water column (OWC) ocean-wave energy converter. | 2 | Students should be aware that energy from a water wave can be extracted in a variety of different ways, but only a description of the OWC is required. |
| 8.4.22 | Determine the power per unit length of a wavefront, assuming a rectangular profile for the wave. | 3 | |
| 8.4.23 | Solve problems involving wave power. | 3 | |

## 8.5 Greenhouse effect

**3 hours**

**Aim 7:** Computer simulation, spreadsheets and databases have a significant role here.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Solar radiation** | | | |
| 8.5.1 | Calculate the intensity of the Sun's radiation incident on a planet. | 2 | |
| 8.5.2 | Define *albedo*. | 1 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 8.5.3 | State factors that determine a planet's albedo. | 1 | Students should know that the Earth's albedo varies daily and is dependent on season (cloud formations) and latitude. Oceans have a low value but snow a high value. The global annual mean albedo is 0.3 (30%) on Earth. |
| **The greenhouse effect** | | | |
| 8.5.4 | Describe the greenhouse effect. | 2 | |
| 8.5.5 | Identify the main greenhouse gases and their sources. | 2 | The gases to be considered are $CH_4$, $H_2O$, $CO_2$ and $N_2O$. It is sufficient for students to know that each has natural and man-made origins. |
| 8.5.6 | Explain the molecular mechanisms by which greenhouse gases absorb infrared radiation. | 3 | Students should be aware of the role played by resonance. The natural frequency of oscillation of the molecules of greenhouse gases is in the infrared region. |
| 8.5.7 | Analyse absorption graphs to compare the relative effects of different greenhouse gases. | 3 | Students should be familiar with, but will not be expected to remember, specific details of graphs showing infrared transmittance through a gas. |
| 8.5.8 | Outline the nature of black-body radiation. | 2 | Students should know that black-body radiation is the radiation emitted by a "perfect" emitter. |
| 8.5.9 | Draw and annotate a graph of the emission spectra of black bodies at different temperatures. | 2 | |
| 8.5.10 | State the Stefan–Boltzmann law and apply it to compare emission rates from different surfaces. | 2 | |
| 8.5.11 | Apply the concept of emissivity to compare the emission rates from the different surfaces. | 2 | |
| 8.5.12 | Define *surface heat capacity* $C_s$. | 1 | Surface heat capacity is the energy required to raise the temperature of unit area of a planet's surface by one degree, and is measured in J $m^{-2}$ $K^{-1}$. |
| 8.5.13 | Solve problems on the greenhouse effect and the heating of planets using a simple energy balance climate model. | 3 | Students should appreciate that the change of a planet's temperature over a period of time is given by:<br>(incoming radiation intensity – outgoing radiation intensity) × time / surface heat capacity.<br>Students should be aware of limitations of the model and suggest how it may be improved.<br>**Aim 7:** A spreadsheet should be used to show a simple climate model. Computer simulations could be used to show more complex models (see OCC for details).<br>**TOK:** The use and importance of computer modelling can be explained as a powerful means by which knowledge may be gained. |

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## 8.6 Global warming

**3 hours**

**Int:** The importance of the international dimension in scientific research to solve global problems can be demonstrated here.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Global warming** | | | |
| 8.6.1 | Describe some possible models of global warming. | 2 | Students must be aware that a range of models has been suggested to explain global warming, including changes in the composition of greenhouse gases in the atmosphere, increased solar flare activity, cyclical changes in the Earth's orbit and volcanic activity. |
| 8.6.2 | State what is meant by the enhanced greenhouse effect. | 1 | It is sufficient for students to be aware that enhancement of the greenhouse effect is caused by human activities. |
| 8.6.3 | Identify the increased combustion of fossil fuels as the likely major cause of the enhanced greenhouse effect. | 2 | Students should be aware that, although debatable, the generally accepted view of most scientists is that human activities, mainly related to burning of fossil fuels, have released extra carbon dioxide into the atmosphere. |
| 8.6.4 | Describe the evidence that links global warming to increased levels of greenhouse gases. | 2 | For example, international ice core research produces evidence of atmospheric composition and mean global temperatures over thousands of years (ice cores up to 420,000 years have been drilled in the Russian Antarctic base, Vostok). |
| 8.6.5 | Outline some of the mechanisms that may increase the rate of global warming. | 2 | Students should know that:<br>• global warming reduces ice/snow cover, which in turn changes the albedo, to increase rate of heat absorption<br>• temperature increase reduces the solubility of $CO_2$ in the sea and increases atmospheric concentrations<br>• deforestation reduces carbon fixation. |
| 8.6.6 | Define *coefficient of volume expansion*. | 1 | Students should know that the coefficient of volume expansion is the fractional change in volume per degree change in temperature. |
| 8.6.7 | State that one possible effect of the enhanced greenhouse effect is a rise in mean sea-level. | 1 | |
| 8.6.8 | Outline possible reasons for a predicted rise in mean sea-level. | 2 | Students should be aware that precise predictions are difficult to make due to factors such as:<br>• anomalous expansion of water<br>• different effects of ice melting on sea water compared to ice melting on land. |
| 8.6.9 | Identify climate change as an outcome of the enhanced greenhouse effect. | 2 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 8.6.10 | Solve problems related to the enhanced greenhouse effect. | 3 | Problems could involve volume expansion, specific heat capacity and latent heat. |
| 8.6.11 | Identify some possible solutions to reduce the enhanced greenhouse effect. | 2 | Students should be aware of the following:<br>• greater efficiency of power production<br>• replacing the use of coal and oil with natural gas<br>• use of combined heating and power systems (CHP)<br>• increased use of renewable energy sources and nuclear power<br>• carbon dioxide capture and storage<br>• use of hybrid vehicles. |
| 8.6.12 | Discuss international efforts to reduce the enhanced greenhouse effect. | 3 | These should include, for example:<br>• Intergovernmental Panel on Climate Change (IPCC)<br>• Kyoto Protocol<br>• Asia-Pacific Partnership on Clean Development and Climate (APPCDC). |

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# Syllabus details—AHL

## Topic 9: Motion in fields (8 hours)

As in topic 6, the similarities and differences between the fields also apply to potential.

**Aim 7:** This topic lends itself to the use of modelling with spreadsheets and simulations to illustrate the concepts addressed.

**TOK:** This topic includes how fundamental concepts may be applied to different phenomena.

### 9.1 Projectile motion

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 9.1.1 | State the independence of the vertical and the horizontal components of velocity for a projectile in a uniform field. | 1 | |
| 9.1.2 | Describe and sketch the trajectory of projectile motion as parabolic in the absence of air resistance. | 3 | Proof of the parabolic nature of the trajectory is not required. |
| 9.1.3 | Describe qualitatively the effect of air resistance on the trajectory of a projectile. | 2 | |
| 9.1.4 | Solve problems on projectile motion. | 3 | Problems may involve projectiles launched horizontally or at any angle above or below the horizontal. Applying conservation of energy may provide a simpler solution to some problems than using projectile motion kinematics equations. |


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## 9.2 Gravitational field, potential and energy

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 9.2.1 | Define *gravitational potential* and *gravitational potential energy*. | 1 | Students should understand the scalar nature of gravitational potential and that the potential at infinity is taken as zero.<br>Students should understand that the work done in moving a mass between two points in a gravitational field is independent of the path taken. |
| 9.2.2 | State and apply the expression for gravitational potential due to a point mass. | 2 | |
| 9.2.3 | State and apply the formula relating gravitational field strength to gravitational potential gradient. | 2 | |
| 9.2.4 | Determine the potential due to one or more point masses. | 3 | |
| 9.2.5 | Describe and sketch the pattern of equipotential surfaces due to one and two point masses. | 3 | |
| 9.2.6 | State the relation between equipotential surfaces and gravitational field lines. | 1 | |

## 9.3 Electric field, potential and energy

**2 hours**

This sub-topic has direct analogies with the preceding one and also links to sub-topic 5.1 on electric potential difference.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 9.3.1 | Define *electric potential* and *electric potential energy*. | 1 | Students should understand the scalar nature of electric potential and that the potential at infinity is taken as zero.<br>Students should understand that the work done in moving a point charge between two points in an electric field is independent of the path taken. |
| 9.3.2 | State and apply the expression for electric potential due to a point charge. | 2 | |
| 9.3.3 | State and apply the formula relating electric field strength to electric potential gradient. | 2 | |
| 9.3.4 | Determine the potential due to one or more point charges. | 3 | |
| 9.3.5 | Describe and sketch the pattern of equipotential surfaces due to one and two point charges. | 3 | |
| 9.3.6 | State the relation between equipotential surfaces and electric field lines. | 1 | |

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| | Assessment statement | Obj | Teacher's notes | | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|---|---|---|---|
| 9.2.7 | Explain the concept of escape speed from a planet. | 3 | | | | | |
| 9.2.8 | Derive an expression for the escape speed of an object from the surface of a planet. | 3 | Students should appreciate the simplifying assumptions in this derivation. | | | | |
| 9.2.9 | Solve problems involving gravitational potential energy and gravitational potential. | 3 | | 9.3.7 | Solve problems involving electric potential energy and electric potential. | 3 | |


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## 9.4 Orbital motion

**2 hours**

Although orbital motion may be circular, elliptical or parabolic, this sub-topic only deals with circular orbits. This sub-topic is not fundamentally new physics, but an application that synthesizes ideas from gravitation, circular motion, dynamics and energy.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 9.4.1 | State that gravitation provides the centripetal force for circular orbital motion. | 1 | |
| 9.4.2 | Derive Kepler's third law. | 3 | |
| 9.4.3 | Derive expressions for the kinetic energy, potential energy and total energy of an orbiting satellite. | 3 | |
| 9.4.4 | Sketch graphs showing the variation with orbital radius of the kinetic energy, gravitational potential energy and total energy of a satellite. | 3 | |
| 9.4.5 | Discuss the concept of "weightlessness" in orbital motion, in free fall and in deep space. | 3 | |
| 9.4.6 | Solve problems involving orbital motion. | 3 | |

# Topic 10: Thermal physics (6 hours)

## 10.1 Thermodynamics

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Gas laws** | | | |
| 10.1.1 | State the equation of state for an ideal gas. | 1 | Students should be aware that an ideal gas is one that has the equation of state $PV = nRT$ and that this equation also defines the universal gas constant $R$. |
| 10.1.2 | Describe the difference between an ideal gas and a real gas. | 2 | Students should be aware of the circumstances in which real gas behaviour approximates to ideal gas behaviour. Students should also appreciate that ideal gases cannot be liquefied. |
| 10.1.3 | Describe the concept of the absolute zero of temperature and the Kelvin scale of temperature. | 2 | |
| 10.1.4 | Solve problems using the equation of state of an ideal gas. | 3 | |

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## 10.2 Processes

**3 hours**

Although there are many thermodynamic systems, in this sub-topic discussion will be restricted to a fixed mass of an ideal gas.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The first law of thermodynamics** | | | |
| 10.2.1 | Deduce an expression for the work involved in a volume change of a gas at constant pressure. | 3 | |
| 10.2.2 | State the first law of thermodynamics. | 1 | Students should be familiar with the terms system and surroundings. They should also appreciate that if a system and its surroundings are at different temperatures and the system undergoes a process, the energy transferred by non-mechanical means to or from the system is referred to as thermal energy (heat). |
| 10.2.3 | Identify the first law of thermodynamics as a statement of the principle of energy conservation. | 2 | |
| 10.2.4 | Describe the isochoric (isovolumetric), isobaric, isothermal and adiabatic changes of state of an ideal gas. | 2 | In each process, the energy transferred, the work done and the internal energy change should be addressed. Students should realize that a rapid compression or expansion of a gas is approximately adiabatic. |
| 10.2.5 | Draw and annotate thermodynamic processes and cycles on *P*–*V* diagrams. | 2 | |
| 10.2.6 | Calculate from a *P*–*V* diagram the work done in a thermodynamic cycle. | 2 | |
| 10.2.7 | Solve problems involving state changes of a gas. | 3 | |

## 10.3 Second law of thermodynamics and entropy

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 10.3.1 | State that the second law of thermodynamics implies that thermal energy cannot spontaneously transfer from a region of low temperature to a region of high temperature. | 1 | |
| 10.3.2 | State that entropy is a system property that expresses the degree of disorder in the system. | 1 | |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 10.3.3 | State the second law of thermodynamics in terms of entropy changes. | 1 | A statement that the overall entropy of the universe is increasing will suffice or that all natural processes increase the entropy of the universe. |
| 10.3.4 | Discuss examples of natural processes in terms of entropy changes. | 3 | Students should understand that, although local entropy may decrease, any process will increase the total entropy of the system and surroundings, that is, the universe. |

# Topic 11: Wave phenomena (12 hours)

**Aim 7:** Computer simulations could be very helpful in illustrating concepts introduced in this topic.

## 11.1 Standing (stationary) waves

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 11.1.1 | Describe the nature of standing (stationary) waves. | 2 | Students should consider energy transfer, amplitude and phase. |
| 11.1.2 | Explain the formation of one-dimensional standing waves. | 3 | Students should understand what is meant by nodes and antinodes. |
| 11.1.3 | Discuss the modes of vibration of strings and air in open and in closed pipes. | 3 | The lowest-frequency mode is known either as the fundamental or as the first harmonic. The term overtone will not be used. |
| 11.1.4 | Compare standing waves and travelling waves. | 3 | |
| 11.1.5 | Solve problems involving standing waves. | 3 | |

## 11.2 Doppler effect

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 11.2.1 | Describe what is meant by the Doppler effect. | 2 | |
| 11.2.2 | Explain the Doppler effect by reference to wavefront diagrams for moving-detector and moving-source situations. | 3 | |
| 11.2.3 | Apply the Doppler effect equations for sound. | 2 | |
| 11.2.4 | Solve problems on the Doppler effect for sound. | 3 | Problems will not include situations where both source and detector are moving. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 11.2.5 | Solve problems on the Doppler effect for electromagnetic waves using the approximation $\Delta f = \frac{v}{c} f$. | 3 | Students should appreciate that the approximation may be used only when $v \ll c$. |
| 11.2.6 | Outline an example in which the Doppler effect is used to measure speed. | 2 | Suitable examples include blood-flow measurements and the measurement of vehicle speeds. |

## 11.3 Diffraction

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Diffraction at a single slit** | | | |
| 11.3.1 | Sketch the variation with angle of diffraction of the relative intensity of light diffracted at a single slit. | 3 | |
| 11.3.2 | Derive the formula $\theta = \frac{\lambda}{b}$ for the position of the first minimum of the diffraction pattern produced at a single slit. | 3 | |
| 11.3.3 | Solve problems involving single-slit diffraction. | 3 | |

## 11.4 Resolution

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 11.4.1 | Sketch the variation with angle of diffraction of the relative intensity of light emitted by two point sources that has been diffracted at a single slit. | 3 | Students should sketch the variation where the diffraction patterns are well resolved, just resolved and not resolved. |
| 11.4.2 | State the Rayleigh criterion for images of two sources to be just resolved. | 1 | Students should know that the criterion for a circular aperture is $\theta = 1.22\frac{\lambda}{b}$. |
| 11.4.3 | Describe the significance of resolution in the development of devices such as CDs and DVDs, the electron microscope and radio telescopes. | 2 | |
| 11.4.4 | Solve problems involving resolution. | 3 | Problems could involve the human eye and optical instruments. |


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## 11.5 Polarization

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 11.5.1 | Describe what is meant by polarized light. | 2 | |
| 11.5.2 | Describe polarization by reflection. | 2 | This may be illustrated using light or microwaves. The use of polarized sunglasses should be included. |
| 11.5.3 | State and apply Brewster's law. | 2 | |
| 11.5.4 | Explain the terms polarizer and analyser. | 3 | |
| 11.5.5 | Calculate the intensity of a transmitted beam of polarized light using Malus' law. | 2 | |
| 11.5.6 | Describe what is meant by an optically active substance. | 2 | Students should be aware that such substances rotate the plane of polarization. |
| 11.5.7 | Describe the use of polarization in the determination of the concentration of certain solutions. | 2 | |
| 11.5.8 | Outline qualitatively how polarization may be used in stress analysis. | 2 | |
| 11.5.9 | Outline qualitatively the action of liquid-crystal displays (LCDs). | 2 | **Aim 8:** The use of LCD screens in a wide variety of different applications/devices can be mentioned. |
| 11.5.10 | Solve problems involving the polarization of light. | 3 | |

# Topic 12: Electromagnetic induction (6 hours)

## 12.1 Induced electromotive force (emf)

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 12.1.1 | Describe the inducing of an emf by relative motion between a conductor and a magnetic field. | 2 | |
| 12.1.2 | Derive the formula for the emf induced in a straight conductor moving in a magnetic field. | 3 | Students should be able to derive the expression<br>induced emf = $Blv$<br>without using Faraday's law. |
| 12.1.3 | Define *magnetic flux* and *magnetic flux linkage*. | 1 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 12.1.4 | Describe the production of an induced emf by a time-changing magnetic flux. | 2 | |
| 12.1.5 | State Faraday's law and Lenz's law. | 1 | |
| 12.1.6 | Solve electromagnetic induction problems. | 3 | |

## 12.2 Alternating current

**2 hours**

**Aim 7:** Computer simulations of ac generators are a useful means to assess understanding.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 12.2.1 | Describe the emf induced in a coil rotating within a uniform magnetic field. | 2 | Students should understand, without any derivation, that the induced emf is sinusoidal if the rotation is at constant speed. |
| 12.2.2 | Explain the operation of a basic alternating current (ac) generator. | 3 | |
| 12.2.3 | Describe the effect on the induced emf of changing the generator frequency. | 2 | Students will be expected to compare the output from generators operating at different frequencies by sketching appropriate graphs. |
| 12.2.4 | Discuss what is meant by the root mean squared (rms) value of an alternating current or voltage. | 3 | Students should know that the rms value of an alternating current (or voltage) is that value of the direct current (or voltage) that dissipates power in a resistor at the same rate. The rms value is also known as the rating. |
| 12.2.5 | State the relation between peak and rms values for sinusoidal currents and voltages. | 1 | |
| 12.2.6 | Solve problems using peak and rms values. | 3 | |
| 12.2.7 | Solve ac circuit problems for ohmic resistors. | 3 | |
| 12.2.8 | Describe the operation of an ideal transformer. | 2 | |
| 12.2.9 | Solve problems on the operation of ideal transformers. | 3 | |

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## 12.3 Transmission of electrical power

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 12.3.1 | Outline the reasons for power losses in transmission lines and real transformers. | 2 | |
| 12.3.2 | Explain the use of high-voltage step-up and step-down transformers in the transmission of electrical power. | 3 | Students should be aware that, for economic reasons, there is no ideal value of voltage for electrical transmission. |
| 12.3.3 | Solve problems on the operation of real transformers and power transmission. | 3 | |
| 12.3.4 | Suggest how extra-low-frequency electromagnetic fields, such as those created by electrical appliances and power lines, induce currents within a human body. | 3 | |
| 12.3.5 | Discuss some of the possible risks involved in living and working near high-voltage power lines. | 3 | Students should be aware that current experimental evidence suggests that low-frequency fields do not harm genetic material.<br>Students should appreciate that the risks attached to the inducing of current in the body are not fully understood. These risks are likely to be dependent on current (density), frequency and length of exposure.<br>**Aim 8 and TOK:** The use of risk assessment in making scientific decisions can be discussed here. The issues of correlation and cause, and the limitations of data, are also relevant here. |

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# Topic 13: Quantum physics and nuclear physics (15 hours)

**TOK:** This topic raises fundamental philosophical problems related to the nature of observation and measurement. The concept of paradigm shift can be developed here.

## 13.1 Quantum physics

**10 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The quantum nature of radiation** | | | |
| 13.1.1 | Describe the photoelectric effect. | 2 | |
| 13.1.2 | Describe the concept of the photon, and use it to explain the photoelectric effect. | 3 | Students should be able to explain why the wave model of light is unable to account for the photoelectric effect, and be able to describe and explain the Einstein model. |
| 13.1.3 | Describe and explain an experiment to test the Einstein model. | 3 | Millikan's experiment involving the application of a stopping potential would be suitable. |
| 13.1.4 | Solve problems involving the photoelectric effect. | 3 | |
| **The wave nature of matter** | | | |
| 13.1.5 | Describe the de Broglie hypothesis and the concept of matter waves. | 2 | Students should also be aware of wave–particle duality (the dual nature of both radiation and matter). |
| 13.1.6 | Outline an experiment to verify the de Broglie hypothesis. | 2 | A brief outline of the Davisson–Germer experiment will suffice. |
| 13.1.7 | Solve problems involving matter waves. | 3 | For example, students should be able to calculate the wavelength of electrons after acceleration through a given potential difference. |
| **Atomic spectra and atomic energy states** | | | |
| 13.1.8 | Outline a laboratory procedure for producing and observing atomic spectra. | 2 | Students should be able to outline procedures for both emission and absorption spectra. Details of the spectrometer are not required. |
| 13.1.9 | Explain how atomic spectra provide evidence for the quantization of energy in atoms. | 3 | An explanation in terms of energy differences between allowed electron energy states is sufficient. |
| 13.1.10 | Calculate wavelengths of spectral lines from energy level differences and vice versa. | 2 | **Aim 7:** Computer simulations showing the link between energy level transitions and spectral lines assist understanding. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 13.1.11 | Explain the origin of atomic energy levels in terms of the "electron in a box" model. | 3 | The model assumes that, if an electron is confined to move in one dimension by a box, the de Broglie waves associated with the electron will be standing waves of wavelength $\frac{2L}{n}$ where $L$ is the length of the box and $n$ is a positive integer. Students should be able to show that the kinetic energy $E_K$ of the electron in the box is $\frac{n^2h^2}{8m_eL^2}$. |
| 13.1.12 | Outline the Schrödinger model of the hydrogen atom. | 2 | The model assumes that electrons in the atom may be described by wavefunctions. The electron has an undefined position, but the square of the amplitude of the wavefunction gives the probability of finding the electron at a particular point. |
| 13.1.13 | Outline the Heisenberg uncertainty principle with regard to position–momentum and time–energy. | 2 | Students should be aware that the conjugate quantities, position–momentum and time–energy, cannot be known precisely at the same time. They should know of the link between the uncertainty principle and the de Broglie hypothesis. For example, students should know that, if a particle has a uniquely defined de Broglie wavelength, then its momentum is known precisely but all knowledge of its position is lost. |

## 13.2 Nuclear physics

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 13.2.1 | Explain how the radii of nuclei may be estimated from charged particle scattering experiments. | 3 | Use of energy conservation for determining closest-approach distances for Coulomb scattering experiments is sufficient. |
| 13.2.2 | Describe how the masses of nuclei may be determined using a Bainbridge mass spectrometer. | 2 | Students should be able to draw a schematic diagram of the Bainbridge mass spectrometer, but the experimental details are not required.<br>Students should appreciate that nuclear mass values provide evidence for the existence of isotopes. |
| 13.2.3 | Describe one piece of evidence for the existence of nuclear energy levels. | 2 | For example, alpha (α) particles produced by the decay of a nucleus have discrete energies; gamma-ray (γ-ray) spectra are discrete.<br>Students should appreciate that the nucleus, like the atom, is a quantum system and, as such, has discrete energy levels. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Radioactive decay** | | | |
| 13.2.4 | Describe $\beta^+$ decay, including the existence of the neutrino. | 2 | Students should know that β energy spectra are continuous, and that the neutrino was postulated to account for these spectra. |
| 13.2.5 | State the radioactive decay law as an exponential function and define the *decay constant*. | 1 | Students should know that the decay constant is defined as the probability of decay of a nucleus per unit time. |
| 13.2.6 | Derive the relationship between decay constant and half-life. | 3 | |
| 13.2.7 | Outline methods for measuring the half-life of an isotope. | 2 | Students should know the principles of measurement for both long and short half-lives. |
| 13.2.8 | Solve problems involving radioactive half-life. | 3 | |

# Topic 14: Digital technology (8 hours)

**Aim 8** and **Int:** This topic shows how technological advances involving many different applications are based on fundamental physics. The implications for society of the rapid pace of technological innovation can be discussed.

## 14.1 Analogue and digital signals

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 14.1.1 | Solve problems involving the conversion between binary numbers and decimal numbers. | 3 | Students should be aware of the term bit. An awareness of the least-significant bit (LSB) and most-significant bit (MSB) is required. Problems will be limited to a maximum of five bits in digital numbers. |
| 14.1.2 | Describe different means of storage of information in both analogue and digital forms. | 2 | Students may consider LPs, cassette tapes, floppy disks, hard disks, CDs, DVDs, and so on. |
| 14.1.3 | Explain how interference of light is used to recover information stored on a CD. | 3 | Students must know that destructive interference occurs when light is reflected from the edge of a pit. |
| 14.1.4 | Calculate an appropriate depth for a pit from the wavelength of the laser light. | 2 | |
| 14.1.5 | Solve problems on CDs and DVDs related to data storage capacity. | 3 | |
| 14.1.6 | Discuss the advantage of the storage of information in digital rather than analogue form. | 3 | Students should consider quality, reproducibility, retrieval speed, portability of stored data and manipulation of data. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 14.1.7 | Discuss the implications for society of ever-increasing capability of data storage. | 3 | Teachers should consider moral, ethical, social, economic and environmental implications. |

## 14.2 Data capture; digital imaging using charge-coupled devices (CCDs)

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| 14.2.1 | Define *capacitance*. | 1 | |
| 14.2.2 | Describe the structure of a charge-coupled device (CCD). | 2 | Students should know that a CCD is a silicon chip divided into small areas called pixels. Each pixel can be considered to behave as a capacitor. |
| 14.2.3 | Explain how incident light causes charge to build up within a pixel. | 3 | Students are required to use the photoelectric effect. |
| 14.2.4 | Outline how the image on a CCD is digitized. | 2 | Students are only required to know that an electrode measures the potential difference developed across each pixel and this is then converted into a digital signal. The pixel position is also stored. |
| 14.2.5 | Define *quantum efficiency* of a pixel. | 1 | Quantum efficiency is the ratio of the number of photoelectrons emitted to the number of photons incident on the pixel. |
| 14.2.6 | Define *magnification*. | 1 | Students are required to know that magnification is the ratio of the length of the image on the CCD to the length of the object. |
| 14.2.7 | State that two points on an object may be just resolved on a CCD if the images of the points are at least two pixels apart. | 1 | |
| 14.2.8 | Discuss the effects of quantum efficiency, magnification and resolution on the quality of the processed image. | 3 | |
| 14.2.9 | Describe a range of practical uses of a CCD, and list some advantages compared with the use of film. | 2 | Students should appreciate that CCDs are used for image capturing in a large range of the electromagnetic spectrum. They should consider items such as digital cameras, video cameras, telescopes, including the Hubble Telescope, and medical X-ray imaging. |
| 14.2.10 | Outline how the image stored in a CCD is retrieved. | 2 | |
| 14.2.11 | Solve problems involving the use of CCDs. | 3 | |

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# Syllabus details—Options SL

These options are available at SL only.

A2–A6 are identical to 11.1–11.5.

B1–B2 are identical to 13.1–13.2.

C1–C2 are identical to 14.1–14.2.

C3–C4 are identical to F5–F6.

D1–D3 are identical to H1–H3.

D4 and D5 are identical to J1 and J3.

## Option A: Sight and wave phenomena (15 hours)

**Aim 7:** Computer simulations could be very helpful in illustrating the different ideas in this option.

### A1 The eye and sight

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| A.1.1 | Describe the basic structure of the human eye. | 2 | The structure should be limited to those features affecting the physical operation of the eye. |
| A.1.2 | State and explain the process of depth of vision and accommodation. | 3 | The near point and the far point of the eye for normal vision are also included. |
| A.1.3 | State that the retina contains rods and cones, and describe the variation in density across the surface of the retina. | 2 | |
| A.1.4 | Describe the function of the rods and of the cones in photopic and scotopic vision. | 2 | Students should be able to sketch and interpret spectral response graphs and give an explanation for colour blindness. |
| A.1.5 | Describe colour mixing of light by addition and subtraction. | 2 | Students should be able to "identify" primary and secondary colours. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| A.1.6 | Discuss the effect of light and dark, and colour, on the perception of objects. | 3 | Students should consider architectural effects of light and shadow (for example, deep shadow gives the impression of massiveness). Glow can be used to give an impression of "warmth" (for example, blue tints are cold) or to change the perceived size of a room (for example, light-coloured ceilings heighten the room).<br>**TOK:** This can contribute to a discussion on perception. |

Wave phenomena: (A2–A6 are identical to 11.1–11.5).

## A2 Standing (stationary) waves

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| A.2.1 | Describe the nature of standing (stationary) waves. | 2 | Students should consider energy transfer, amplitude and phase. |
| A.2.2 | Explain the formation of one-dimensional standing waves. | 3 | Students should understand what is meant by nodes and antinodes. |
| A.2.3 | Discuss the modes of vibration of strings and air in open and in closed pipes. | 3 | The lowest-frequency mode is known either as the fundamental or as the first harmonic. The term overtone will not be used. |
| A.2.4 | Compare standing waves and travelling waves. | 3 | |
| A.2.5 | Solve problems involving standing waves. | 3 | |

## A3 Doppler effect

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| A.3.1 | Describe what is meant by the Doppler effect. | 2 | |
| A.3.2 | Explain the Doppler effect by reference to wavefront diagrams for moving-detector and moving-source situations. | 3 | |
| A.3.3 | Apply the Doppler effect equations for sound. | 2 | |
| A.3.4 | Solve problems on the Doppler effect for sound. | 3 | Problems will not include situations where both source and detector are moving. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| A.3.5 | Solve problems on the Doppler effect for electromagnetic waves using the approximation $\Delta f = \frac{v}{c} f$. | 3 | Students should appreciate that the approximation may be used only when $v \ll c$. |
| A.3.6 | Outline an example in which the Doppler effect is used to measure speed. | 2 | Suitable examples include blood-flow measurements and the measurement of vehicle speeds. |

## A4 Diffraction

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Diffraction at a single slit** | | | |
| A.4.1 | Sketch the variation with angle of diffraction of the relative intensity of light diffracted at a single slit. | 3 | |
| A.4.2 | Derive the formula $\theta = \frac{\lambda}{b}$ for the position of the first minimum of the diffraction pattern produced at a single slit. | 3 | |
| A.4.3 | Solve problems involving single-slit diffraction. | 3 | |

## A5 Resolution

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| A.5.1 | Sketch the variation with angle of diffraction of the relative intensity of light emitted by two point sources that has been diffracted at a single slit. | 3 | Students should sketch the variation where the diffraction patterns are well resolved, just resolved and not resolved. |
| A.5.2 | State the Rayleigh criterion for images of two sources to be just resolved. | 1 | Students should know that the criterion for a circular aperture is $\theta = 1.22\frac{\lambda}{b}$. |
| A.5.3 | Describe the significance of resolution in the development of devices such as CDs and DVDs, the electron microscope and radio telescopes. | 2 | |
| A.5.4 | Solve problems involving resolution. | 3 | Problems could involve the human eye and optical instruments. |


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# A6 Polarization

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| A.6.1 | Describe what is meant by polarized light. | 2 | |
| A.6.2 | Describe polarization by reflection. | 2 | This may be illustrated using light or microwaves. The use of polarized sunglasses should be included. |
| A.6.3 | State and apply Brewster's law. | 2 | |
| A.6.4 | Explain the terms polarizer and analyser. | 3 | |
| A.6.5 | Calculate the intensity of a transmitted beam of polarized light using Malus' law. | 2 | |
| A.6.6 | Describe what is meant by an optically active substance. | 2 | Students should be aware that such substances rotate the plane of polarization. |
| A.6.7 | Describe the use of polarization in the determination of the concentration of certain solutions. | 2 | |
| A.6.8 | Outline qualitatively how polarization may be used in stress analysis. | 2 | |
| A.6.9 | Outline qualitatively the action of liquid-crystal displays (LCDs). | 2 | **Aim 8:** The use of LCD screens in a wide variety of different applications/devices can be mentioned. |
| A.6.10 | Solve problems involving the polarization of light. | 3 | |

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# Option B: Quantum physics and nuclear physics (15 hours)

**TOK:** This option raises fundamental philosophical problems related to the nature of observation and measurement. The concept of paradigm shift can be developed here.

B1–B2 are identical to 13.1–13.2.

## B1 Quantum physics

**10 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The quantum nature of radiation** | | | |
| B.1.1 | Describe the photoelectric effect. | 2 | |
| B.1.2 | Describe the concept of the photon and use it to explain the photoelectric effect. | 3 | Students should be able to explain why the wave model of light is unable to account for the photoelectric effect, and be able to describe and explain the Einstein model. |
| B.1.3 | Describe and explain an experiment to test the Einstein model. | 3 | Millikan's experiment involving the application of a stopping potential would be suitable. |
| B.1.4 | Solve problems involving the photoelectric effect. | 3 | |
| **The wave nature of matter** | | | |
| B.1.5 | Describe the de Broglie hypothesis and the concept of matter waves. | 2 | Students should also be aware of wave–particle duality (the dual nature of both radiation and matter). |
| B.1.6 | Outline an experiment to verify the de Broglie hypothesis. | 2 | A brief outline of the Davisson–Germer experiment will suffice. |
| B.1.7 | Solve problems involving matter waves. | 3 | For example, students should be able to calculate the wavelength of electrons after acceleration through a given potential difference. |
| **Atomic spectra and atomic energy states** | | | |
| B.1.8 | Outline a laboratory procedure for producing and observing atomic spectra. | 2 | Students should be able to outline procedures for both emission and absorption spectra. Details of the spectrometer are not required. |
| B.1.9 | Explain how atomic spectra provide evidence for the quantization of energy in atoms. | 3 | An explanation in terms of energy differences between allowed electron energy states is sufficient. |
| B.1.10 | Calculate wavelengths of spectral lines from energy level differences and vice versa. | 2 | **Aim 7:** Computer simulations showing the link between energy level transitions and spectral lines assist understanding. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| B.1.11 | Explain the origin of atomic energy levels in terms of the "electron in a box" model. | 3 | The model assumes that, if an electron is confined to move in one dimension by a box, the de Broglie waves associated with the electron will be standing waves of wavelength $\frac{2L}{n}$ where $L$ is the length of the box and $n$ is a positive integer. Students should be able to show that the kinetic energy $E_K$ of the electron in the box is given by $\frac{n^2h^2}{8m_eL^2}$. |
| B.1.12 | Outline the Schrödinger model of the hydrogen atom. | 2 | The model assumes that electrons in the atom may be described by wavefunctions. The electron has an undefined position, but the square of the amplitude of the wavefunction gives the probability of finding the electron at a particular point. |
| B.1.13 | Outline the Heisenberg uncertainty principle with regard to position–momentum and time–energy. | 2 | Students should be aware that the conjugate quantities, position–momentum and time–energy, cannot be known precisely at the same time. They should know of the link between the uncertainty principle and the de Broglie hypothesis. For example, students should know that, if a particle has a uniquely defined de Broglie wavelength, then its momentum is known precisely but all knowledge of its position is lost. |

## B2 Nuclear physics

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| B.2.1 | Explain how the radii of nuclei may be estimated from charged particle scattering experiments. | 3 | Use of energy conservation for determining closest-approach distances for Coulomb scattering experiments is sufficient. |
| B.2.2 | Describe how the masses of nuclei may be determined using a Bainbridge mass spectrometer. | 2 | Students should be able to draw a schematic diagram of the Bainbridge mass spectrometer, but the experimental details are not required.<br>Students should appreciate that nuclear mass values provide evidence for the existence of isotopes. |
| B.2.3 | Describe one piece of evidence for the existence of nuclear energy levels. | 2 | For example, alpha (α) particles produced by the decay of a nucleus have discrete energies; gamma-ray (γ-ray) spectra are discrete.<br>Students should appreciate that the nucleus, like the atom, is a quantum system and, as such, has discrete energy levels. |
| **Radioactive decay** | | | |
| B.2.4 | Describe $\beta^+$ decay, including the existence of the neutrino. | 2 | Students should know that β energy spectra are continuous, and that the neutrino was postulated to account for these spectra. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| B.2.5 | State the radioactive decay law as an exponential function and define the *decay constant*. | 1 | Students should know that the decay constant is defined as the probability of decay of a nucleus per unit time. |
| B.2.6 | Derive the relationship between decay constant and half-life. | 3 | |
| B.2.7 | Outline methods for measuring the half-life of an isotope. | 2 | Students should know the principles of measurement for both long and short half-lives. |
| B.2.8 | Solve problems involving radioactive half-life. | 3 | |

# Option C: Digital technology (15 hours)

**Aim 8** and **Int:** This option shows how technological advances involving many different applications are based on fundamental physics. The implications for society of the rapid pace of technological innovation can be discussed.

C1–C2 are identical to 14.1–14.2.

## C1 Analogue and digital signals

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| C.1.1 | Solve problems involving the conversion between binary numbers and decimal numbers. | 3 | Students should be aware of the term bit. An awareness of the least-significant bit (LSB) and most-significant bit (MSB) is required. Problems will be limited to a maximum of five bits in digital numbers. |
| C.1.2 | Describe different means of storage of information in both analogue and digital forms. | 2 | Students may consider LPs, cassette tapes, floppy disks, hard disks, CDs, DVDs, and so on. |
| C.1.3 | Explain how interference of light is used to recover information stored on a CD. | 3 | Students must know that destructive interference occurs when light is reflected from the edge of a pit. |
| C.1.4 | Calculate an appropriate depth for a pit from the wavelength of the laser light. | 2 | |
| C.1.5 | Solve problems on CDs and DVDs related to data storage capacity. | 3 | |
| C.1.6 | Discuss the advantage of the storage of information in digital rather than analogue form. | 3 | Students should consider quality, reproducibility, retrieval speed, portability of stored data and manipulation of data. |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| C.1.7 | Discuss the implications for society of ever-increasing capability of data storage. | 3 | Teachers should consider moral, ethical, social, economic and environmental implications. |

## C2 Data capture; digital imaging using charge-coupled devices (CCDs)

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| C.2.1 | Define *capacitance*. | 1 | |
| C.2.2 | Describe the structure of a charge-coupled device (CCD). | 2 | Students should know that a CCD is a silicon chip divided into small areas called pixels. Each pixel can be considered to behave as a capacitor. |
| C.2.3 | Explain how incident light causes charge to build up within a pixel. | 3 | Students are required to use the photoelectric effect. |
| C.2.4 | Outline how the image on a CCD is digitized. | 2 | Students are only required to know that an electrode measures the potential difference developed across each pixel and this is then converted into a digital signal. The pixel position is also stored. |
| C.2.5 | Define *quantum efficiency* of a pixel. | 1 | Quantum efficiency is the ratio of the number of photoelectrons emitted to the number of photons incident on the pixel. |
| C.2.6 | Define *magnification*. | 1 | Students are required to know that magnification is the ratio of the length of the image on the CCD to the length of the object. |
| C.2.7 | State that two points on an object may be just resolved on a CCD if the images of the points are at least two pixels apart. | 1 | |
| C.2.8 | Discuss the effects of quantum efficiency, magnification and resolution on the quality of the processed image. | 3 | |
| C.2.9 | Describe a range of practical uses of a CCD, and list some advantages compared with the use of film. | 2 | Students should appreciate that CCDs are used for image capturing in a large range of the electromagnetic spectrum. They should consider items such as digital cameras, video cameras, telescopes, including the Hubble Telescope, and medical X-ray imaging. |
| C.2.10 | Outline how the image stored in a CCD is retrieved. | 2 | |
| C.2.11 | Solve problems involving the use of CCDs. | 3 | |

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C3–C4 are identical to F5–F6.

## C3 Electronics

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| C.3.1 | State the properties of an ideal operational amplifier (op-amp). | 1 | |
| C.3.2 | Draw circuit diagrams for both inverting and non-inverting amplifiers (with a single input) incorporating operational amplifiers. | 1 | |
| C.3.3 | Derive an expression for the gain of an inverting amplifier and for a non-inverting amplifier. | 3 | Students should be aware of the virtual earth approximation. |
| C.3.4 | Describe the use of an operational amplifier circuit as a comparator. | 2 | Students will be expected to draw appropriate circuits. Output devices for comparator circuits may include light-emitting diodes (LEDs) and buzzers. |
| C.3.5 | Describe the use of a Schmitt trigger for the reshaping of digital pulses. | 2 | |
| C.3.6 | Solve problems involving circuits incorporating operational amplifiers. | 3 | |

## C4 The mobile phone system

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| C.4.1 | State that any area is divided into a number of cells (each with its own base station) to which is allocated a range of frequencies. | 1 | Students should know that frequencies are allocated so as to avoid overlap between cells. |
| C.4.2 | Describe the role of the cellular exchange and the public switched telephone network (PSTN) in communications using mobile phones. | 2 | The role of the cellular exchange in the selection and monitoring of base stations and the allocation of channels should be understood. |
| C.4.3 | Discuss the use of mobile phones in multimedia communication. | 3 | |
| C.4.4 | Discuss the moral, ethical, economic, environmental and international issues arising from the use of mobile phones. | 3 | |

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# Option D: Relativity and particle physics (15 hours)

**TOK:** This is an opportunity to introduce the concept of a paradigm shift in relation to scientific understanding. The role of theories and their testing by experiment is crucial here. The meaning of time, the concepts of time dilation and length contraction, the absolute value of the velocity of EM waves are all stimulating ideas for discussion.

Relativity: (D1–D3 are identical to H1–H3).

## D1 Introduction to relativity

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Frames of reference** | | | |
| D.1.1 | Describe what is meant by a frame of reference. | 2 | |
| D.1.2 | Describe what is meant by a Galilean transformation. | 2 | |
| D.1.3 | Solve problems involving relative velocities using the Galilean transformation equations. | 3 | |

## D2 Concepts and postulates of special relativity

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| D.2.1 | Describe what is meant by an inertial frame of reference. | 2 | |
| D.2.2 | State the two postulates of the special theory of relativity. | 1 | |
| D.2.3 | Discuss the concept of simultaneity. | 3 | Students should know that two events occurring at different points in space and which are simultaneous for one observer cannot be simultaneous for another observer in a different frame of reference. |

## D3 Relativistic kinematics

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Time dilation** | | | |
| D.3.1 | Describe the concept of a light clock. | 2 | Only a very simple description is required here. For example, a beam of light reflected between two parallel mirrors may be used to measure time. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| D.3.2 | Define *proper time interval*. | 1 | |
| D.3.3 | Derive the time dilation formula. | 3 | Students should be able to construct a simple derivation of the time dilation formula based on the concept of the light clock and the postulates of relativity. |
| D.3.4 | Sketch and annotate a graph showing the variation with relative velocity of the Lorentz factor. | 3 | |
| D.3.5 | Solve problems involving time dilation. | 3 | |
| **Length contraction** | | | |
| D.3.6 | Define *proper length*. | 1 | |
| D.3.7 | Describe the phenomenon of length contraction. | 2 | The derivation of the length contraction formula is not required. |
| D.3.8 | Solve problems involving length contraction. | 3 | |

Particles: (D4 and D5 are identical to J1 and J3).

## D4 Particles and interactions

**5 hours**

All the material in D4 and D5 is contained in a free CD-Rom produced by CERN (also available on the CERN web site). In D4 and D5 all masses are assumed to be rest masses.

**TOK:** D4 and D5 contain a wealth of material for discussion, for example, the nature of observation, the meaning of measurement, and the meaning of evidence. How developments in one field lead to breakthroughs in another is also a fascinating topic, for example, particle physics and cosmology.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Description and classification of particles** | | | |
| D.4.1 | State what is meant by an elementary particle. | 1 | Particles are called elementary if they have no internal structure, that is, they are not made out of smaller constituents. |
| D.4.2 | Identify elementary particles. | 2 | The classes of elementary particles are quarks, leptons and exchange particles. The Higgs particle could be elementary. |
| D.4.3 | Describe particles in terms of mass and various quantum numbers. | 2 | Students must be aware that particles (elementary as well as composite) are specified in terms of their mass and various quantum numbers. They should consider electric charge, spin, strangeness, colour, lepton number and baryon number. |

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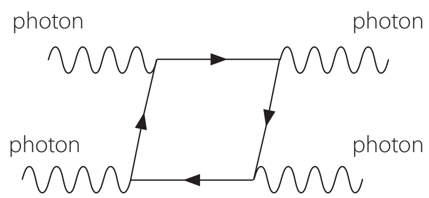
| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| D.4.4 | Classify particles according to spin. | 1 | |
| D.4.5 | State what is meant by an antiparticle. | 1 | |
| D.4.6 | State the Pauli exclusion principle. | 1 | |
| **Fundamental interactions** | | | |
| D.4.7 | List the fundamental interactions. | 1 | Since the early 1970s the electromagnetic and weak interactions have been shown to be two aspects of the same interaction, the electroweak interaction. |
| D.4.8 | Describe the fundamental interactions in terms of exchange particles. | 2 | |
| D.4.9 | Discuss the uncertainty principle for time and energy in the context of particle creation. | 3 | A simple discussion is needed in terms of a particle being created with energy $\Delta E$ existing no longer than a time $\Delta t$ given by $\Delta E \Delta t \geq \frac{h}{4\pi}$ . |
| **Feynman diagrams** | | | |
| D.4.10 | Describe what is meant by a Feynman diagram. | 2 | |
| D.4.11 | Discuss how a Feynman diagram may be used to calculate probabilities for fundamental processes. | 3 | Numerical values of the interaction strengths do not need to be recalled. |
| D.4.12 | Describe what is meant by virtual particles. | 2 | |
| D.4.13 | Apply the formula for the range *R* for interactions involving the exchange of a particle. | 2 | Applications include Yukawa's prediction of the pion or determination of the masses of the $W^{\pm}$, $Z^{0}$ from knowledge of the range of the weak interaction. |
| D.4.14 | Describe pair annihilation and pair production through Feynman diagrams. | 2 | |
| D.4.15 | Predict particle processes using Feynman diagrams. | 3 | For example, the electromagnetic interaction leads to photon–photon scattering (that is, scattering of light by light). The particles in the loop are electrons or positrons:   |

## D5 Quarks

**2 hours**

All the material in D4 and D5 is contained in a free CD-Rom produced by CERN (also available on the CERN web site). In D4 and D5 all masses are assumed to be rest masses.

**TOK:** D4 and D5 contain a wealth of material for discussion, for example, the nature of observation, the meaning of measurement, and the meaning of evidence. How developments in one field lead to breakthroughs in another is also a fascinating topic, for example, particle physics and cosmology.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| D.5.1 | List the six types of quark. | 1 | |
| D.5.2 | State the content, in terms of quarks and antiquarks, of hadrons (that is, baryons and mesons). | 1 | |
| D.5.3 | State the quark content of the proton and the neutron. | 1 | |
| D.5.4 | Define *baryon number* and apply the law of conservation of baryon number. | 2 | Students should know that baryon number is conserved in all reactions. |
| D.5.5 | Deduce the spin structure of hadrons (that is, baryons and mesons). | 3 | Only an elementary discussion in terms of spin "up" and spin "down" is required. |
| D.5.6 | Explain the need for colour in forming bound states of quarks. | 3 | Students should realize that colour is necessary to satisfy the Pauli exclusion principle. The fact that hadrons have no colour is a consequence of confinement. |
| D.5.7 | State the colour of quarks and gluons. | 1 | |
| D.5.8 | Outline the concept of strangeness. | 2 | It is sufficient for students to know that the strangeness of a hadron is the number of anti-strange quarks minus the number of strange quarks it contains.<br>Students must be aware that strangeness is conserved in strong and electromagnetic interactions, but not always in weak interactions. |
| D.5.9 | Discuss quark confinement. | 3 | Students should know that isolated quarks and gluons (that is, particles with colour) cannot be observed. The strong (colour) interaction increases with separation. More hadrons are produced when sufficient energy is supplied to a hadron in order to isolate a quark. |
| D.5.10 | Discuss the interaction that binds nucleons in terms of the colour force between quarks. | 3 | It is sufficient to know that the interaction between nucleons is the residual interaction between the quarks in the nucleons and that this is a short-range interaction. |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# Syllabus details—Options SL and HL

SL students study the core of these options and HL students study the whole option (the core and the extension material).

## Option E: Astrophysics (15/22 hours)

The European Space Agency web site contains material specifically written for this option (see OCC for details).

**Aim 7:** This option allows great scope for the use of ICT. Databases of astronomical data may be assessed, and simulations depicting astronomical processes may be used in teaching and learning. Spreadsheets may be used to model astronomical events. The web sites of large space organizations contain much useful material.

**Aim 8:** The ethical implications of the cost of space research may be discussed.

**Int:** These web sites can also be used to illustrate the international nature of collaboration and research in terms of, for example, telescopes and spacecraft missions.

**TOK:** This option also allows for much discussion of scientific theories (on the nature and origin of the universe) and how those theories are developed and accepted or abandoned.

**Core material:** E1–E4 are core material for SL and HL (15 hours).

**Extension material:** E5–E6 are extension material for HL only (7 hours).

### E1 Introduction to the universe

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The solar system and beyond** | | | |
| E.1.1 | Outline the general structure of the solar system. | 2 | Students should know that the planets orbit the Sun in ellipses and moons orbit planets. (Details of Kepler's laws are not required.) Students should also know the names of the planets, their approximate comparative sizes and comparative distances from the Sun, the nature of comets, and the nature and position of the asteroid belt. |
| E.1.2 | Distinguish between a stellar cluster and a constellation. | 2 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| E.1.3 | Define the *light year.* | 1 | |
| E.1.4 | Compare the relative distances between stars within a galaxy and between galaxies, in terms of order of magnitude. | 3 | |
| E.1.5 | Describe the apparent motion of the stars/constellations over a period of a night and over a period of a year, and explain these observations in terms of the rotation and revolution of the Earth. | 3 | This is the basic background for stellar parallax. Other observations, for example, seasons and the motion of planets, are not expected. |

## E2 Stellar radiation and stellar types

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Energy source** | | | |
| E.2.1 | State that fusion is the main energy source of stars. | 1 | Students should know that the basic process is one in which hydrogen is converted into helium. They do not need to know about the fusion of elements with higher proton numbers. |
| E.2.2 | Explain that, in a stable star (for example, our Sun), there is an equilibrium between radiation pressure and gravitational pressure. | 3 | |
| **Luminosity** | | | |
| E.2.3 | Define the *luminosity* of a star. | 1 | |
| E.2.4 | Define *apparent brightness* and state how it is measured. | 1 | |
| **Wien's law and the Stefan–Boltzmann law** | | | |
| E.2.5 | Apply the Stefan–Boltzmann law to compare the luminosities of different stars. | 2 | |
| E.2.6 | State Wien's (displacement) law and apply it to explain the connection between the colour and temperature of stars. | 2 | |
| **Stellar spectra** | | | |
| E.2.7 | Explain how atomic spectra may be used to deduce chemical and physical data for stars. | 3 | Students must have a qualitative appreciation of the Doppler effect as applied to light, including the terms red-shift and blue-shift. |
| E.2.8 | Describe the overall classification system of spectral classes. | 2 | Students need to refer only to the principal spectral classes (OBAFGKM). |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Types of star** | | | |
| E.2.9 | Describe the different types of star. | 2 | Students need to refer only to single and binary stars, Cepheids, red giants, red supergiants and white dwarfs. Knowledge of different types of Cepheids is not required. |
| E.2.10 | Discuss the characteristics of spectroscopic and eclipsing binary stars. | 3 | |
| **The Hertzsprung–Russell diagram** | | | |
| E.2.11 | Identify the general regions of star types on a Hertzsprung–Russell (HR) diagram. | 2 | Main sequence, red giant, red supergiant, white dwarf and Cepheid stars should be shown, with scales of luminosity and/or absolute magnitude, spectral class and/or surface temperature indicated.<br>Students should be aware that the scale is not linear.<br>Students should know that the mass of main sequence stars is dependent on position on the HR diagram. |

## E3 Stellar distances

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Parallax method** | | | |
| E.3.1 | Define the *parsec*. | 1 | |
| E.3.2 | Describe the stellar parallax method of determining the distance to a star. | 2 | |
| E.3.3 | Explain why the method of stellar parallax is limited to measuring stellar distances less than several hundred parsecs. | 3 | |
| E.3.4 | Solve problems involving stellar parallax. | 3 | |
| **Absolute and apparent magnitudes** | | | |
| E.3.5 | Describe the apparent magnitude scale. | 2 | Students should know that apparent magnitude depends on luminosity and the distance to a star. They should also know that a magnitude 1 star is 100 times brighter than a magnitude 6 star. |
| E.3.6 | Define *absolute magnitude*. | 1 | |
| E.3.7 | Solve problems involving apparent magnitude, absolute magnitude and distance. | 3 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| E.3.8 | Solve problems involving apparent brightness and apparent magnitude. | 3 | |
| **Spectroscopic parallax** | | | |
| E.3.9 | State that the luminosity of a star may be estimated from its spectrum. | 1 | |
| E.3.10 | Explain how stellar distance may be determined using apparent brightness and luminosity. | 3 | |
| E.3.11 | State that the method of spectroscopic parallax is limited to measuring stellar distances less than about 10 Mpc. | 1 | |
| E.3.12 | Solve problems involving stellar distances, apparent brightness and luminosity. | 3 | |
| **Cepheid variables** | | | |
| E.3.13 | Outline the nature of a Cepheid variable. | 2 | Students should know that a Cepheid variable is a star in which the outer layers undergo a periodic expansion and contraction, which produces a periodic variation in its luminosity. |
| E.3.14 | State the relationship between period and absolute magnitude for Cepheid variables. | 1 | |
| E.3.15 | Explain how Cepheid variables may be used as "standard candles". | 3 | It is sufficient for students to know that, if a Cepheid variable is located in a particular galaxy, then the distance to the galaxy may be determined. |
| E.3.16 | Determine the distance to a Cepheid variable using the luminosity–period relationship. | 3 | |

## E4 Cosmology

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Olbers' paradox** | | | |
| E.4.1 | Describe Newton's model of the universe. | 2 | Students should know that Newton assumed an infinite (in space and time), uniform and static universe. |
| E.4.2 | Explain Olbers' paradox. | 3 | Students should be able to show quantitatively, using the inverse square law of luminosity, that Newton's model of the universe leads to a sky that should never be dark. |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The Big Bang model** | | | |
| E.4.3 | Suggest that the red-shift of light from galaxies indicates that the universe is expanding. | 3 | |
| E.4.4 | Describe both space and time as originating with the Big Bang. | 2 | Students should appreciate that the universe is not expanding into a void. |
| E.4.5 | Describe the discovery of cosmic microwave background (CMB) radiation by Penzias and Wilson. | 2 | |
| E.4.6 | Explain how cosmic radiation in the microwave region is consistent with the Big Bang model. | 3 | A simple explanation in terms of the universe "cooling down" is all that is required. |
| E.4.7 | Suggest how the Big Bang model provides a resolution to Olbers' paradox. | 3 | |
| **The development of the universe** | | | |
| E.4.8 | Distinguish between the terms open, flat and closed when used to describe the development of the universe. | 2 | |
| E.4.9 | Define the term *critical density* by reference to a flat model of the development of the universe. | 1 | |
| E.4.10 | Discuss how the density of the universe determines the development of the universe. | 3 | |
| E.4.11 | Discuss problems associated with determining the density of the universe. | 3 | This statement is included to give the students a flavour for the ongoing and complex current nature of research. They should be able to discuss relevant observations and possible explanations. They should recognize that, in common with many other aspects of our universe, much about the phenomena is currently not well understood.<br>Teachers should include dark matter, MACHOs and WIMPs. |
| E.4.12 | State that current scientific evidence suggests that the universe is open. | 1 | |
| E.4.13 | Discuss an example of the international nature of recent astrophysics research. | 3 | It is sufficient for students to outline any astrophysics project that is funded by more than one country. |
| E.4.14 | Evaluate arguments related to investing significant resources into researching the nature of the universe. | 3 | Students should be able to demonstrate their ability to understand the issues involved in deciding priorities for scientific research as well as being able to express their own opinions coherently. |

## HL E5 Stellar processes and stellar evolution

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Nucleosynthesis** | | | |
| E.5.1 | Describe the conditions that initiate fusion in a star. | 2 | |
| E.5.2 | State the effect of a star's mass on the end product of nuclear fusion. | 1 | |
| E.5.3 | Outline the changes that take place in nucleosynthesis when a star leaves the main sequence and becomes a red giant. | 2 | Students need to know an outline only of the processes of helium fusion and silicon fusion to form iron. |
| **Evolutionary paths of stars and stellar processes** | | | |
| E.5.4 | Apply the mass–luminosity relation. | 2 | |
| E.5.5 | Explain how the Chandrasekhar and Oppenheimer–Volkoff limits are used to predict the fate of stars of different masses. | 3 | |
| E.5.6 | Compare the fate of a red giant and a red supergiant. | 3 | Students should know that:<br>• a red giant forms a planetary nebula and then becomes a white dwarf<br>• a white dwarf is stable due to electron degeneracy pressure<br>• a red supergiant experiences a supernova and becomes a neutron star or collapses to a black hole<br>• a neutron star is stable due to neutron degeneracy pressure. |
| E.5.7 | Draw evolutionary paths of stars on an HR diagram. | 1 | |
| E.5.8 | Outline the characteristics of pulsars. | 2 | |

## HL E6 Galaxies and the expanding universe

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Galactic motion** | | | |
| E.6.1 | Describe the distribution of galaxies in the universe. | 2 | Students should understand the terms galactic cluster and galactic supercluster. |
| E.6.2 | Explain the red-shift of light from distant galaxies. | 3 | Students should realize that the red-shift is due to the expansion of the universe. |
| E.6.3 | Solve problems involving red-shift and the recession speed of galaxies. | 3 | |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Hubble's law** | | | |
| E.6.4 | State Hubble's law. | 1 | |
| E.6.5 | Discuss the limitations of Hubble's law. | 3 | |
| E.6.6 | Explain how the Hubble constant may be determined. | 3 | |
| E.6.7 | Explain how the Hubble constant may be used to estimate the age of the universe. | 3 | Students need only consider a constant rate of expansion. |
| E.6.8 | Solve problems involving Hubble's law. | 3 | |
| E.6.9 | Explain how the expansion of the universe made possible the formation of light nuclei and atoms. | 3 | Students should appreciate that, at the very high temperatures of the early universe, only elementary (fundamental) particles could exist and that expansion gave rise to cooling to temperatures at which light nuclei could be stable. |

# Option F: Communications (15/22 hours)

**Core material:** F1–F4 are core material for SL and HL (15 hours).

**Extension material:** F5–F6 are extension material for HL only (7 hours).

## F1 Radio communication

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| F.1.1 | Describe what is meant by the modulation of a wave. | 2 | Students should appreciate that, for information to be carried by a wave, the wave must be changed in some way. |
| F.1.2 | Distinguish between a carrier wave and a signal wave. | 2 | |
| F.1.3 | Describe the nature of amplitude modulation (AM) and frequency modulation (FM). | 2 | For both AM and FM, students should appreciate how the carrier wave is modified in order to transmit the information in the signal wave. |
| F.1.4 | Solve problems based on the modulation of the carrier wave in order to determine the frequency and amplitude of the information signal. | 3 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| F.1.5 | Sketch and analyse graphs of the power spectrum of a carrier wave that is amplitude-modulated by a single-frequency signal. | 3 | |
| F.1.6 | Define what is meant by *sideband frequencies* and *bandwidth*. | 1 | |
| F.1.7 | Solve problems involving sideband frequencies and bandwidth. | 3 | |
| F.1.8 | Describe the relative advantages and disadvantages of AM and FM for radio transmission and reception. | 2 | Students should consider quality, bandwidth, range and cost. |
| F.1.9 | Describe, by means of a block diagram, an AM radio receiver. | 2 | Students should be able to identify and describe the function of each block, including aerial and tuning circuit, RF amplifier, demodulator, AF amplifier and loudspeaker. |

## F2 Digital signals

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| F.2.1 | Solve problems involving the conversion between binary numbers and decimal numbers. | 3 | Students should be aware of the term bit. An awareness of the least-significant bit (LSB) and most-significant bit (MSB) is required. Problems will be limited to a maximum of five bits in digital numbers. |
| F.2.2 | Distinguish between analogue and digital signals. | 2 | |
| F.2.3 | State the advantages of the digital transmission, as compared to the analogue transmission, of information. | 1 | |
| F.2.4 | Describe, using block diagrams, the principles of the transmission and reception of digital signals. | 2 | Students should be able to name and give the function of each block, including sample-and-hold, clock, analogue-to-digital converter (ADC), parallel-to-serial converter, serial-to-parallel converter and digital-to-analogue converter (DAC). |
| F.2.5 | Explain the significance of the number of bits and the bit-rate on the reproduction of a transmitted signal. | 3 | |
| F.2.6 | Describe what is meant by time-division multiplexing. | 2 | |
| F.2.7 | Solve problems involving analogue-to-digital conversion. | 3 | |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| F.2.8 | Describe the consequences of digital communication and multiplexing on worldwide communications. | 2 | Students should be able to discuss cost and availability to the general public, quality of transmission, and the development of means of communication and data sharing such as the Internet. |
| F.2.9 | Discuss the moral, ethical, economic and environmental issues arising from access to the Internet. | 3 | |

## F3 Optic fibre transmission

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| F.3.1 | Explain what is meant by critical angle and total internal reflection. | 3 | |
| F.3.2 | Solve problems involving refractive index and critical angle. | 3 | |
| F.3.3 | Apply the concept of total internal reflection to the transmission of light along an optic fibre. | 2 | Only step-index optic fibres are to be considered. |
| F.3.4 | Describe the effects of material dispersion and modal dispersion. | 2 | Students should appreciate the effects of dispersion on the frequency of pulses that can be transmitted and the development of step-index monomode fibres. |
| F.3.5 | Explain what is meant by attenuation and solve problems involving attenuation measured in decibels (dB). | 3 | |
| F.3.6 | Describe the variation with wavelength of the attenuation of radiation in the core of a monomode fibre. | 2 | Students should be familiar with attenuation per unit length measured in dB $km^{-1}$. Specific values of attenuation are not required. |
| F.3.7 | State what is meant by noise in an optic fibre. | 1 | |
| F.3.8 | Describe the role of amplifiers and reshapers in optic fibre transmission. | 2 | Students should appreciate that reshaping of digital signals being transmitted along an optic fibre reduces the effects of noise. |
| F.3.9 | Solve problems involving optic fibres. | 3 | |

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## F4 Channels of communication

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| F.4.1 | Outline different channels of communication, including wire pairs, coaxial cables, optic fibres, radio waves and satellite communication. | 2 | |
| F.4.2 | Discuss the uses and the relative advantages and disadvantages of wire pairs, coaxial cables, optic fibres and radio waves. | 3 | Students should include noise, attenuation, bandwidth, cost and handling. |
| F.4.3 | State what is meant by a geostationary satellite. | 1 | |
| F.4.4 | State the order of magnitude of the frequencies used for communication with geostationary satellites, and explain why the up-link frequency and the down-link frequency are different. | 3 | |
| F.4.5 | Discuss the relative advantages and disadvantages of the use of geostationary and of polar-orbiting satellites for communication. | 3 | Discussion should include the tracking of satellites, orbital heights and coverage. |
| F.4.6 | Discuss the moral, ethical, economic and environmental issues arising from satellite communication. | 3 | |

## HL F5 Electronics

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| F.5.1 | State the properties of an ideal operational amplifier (op-amp). | 1 | |
| F.5.2 | Draw circuit diagrams for both inverting and non-inverting amplifiers (with a single input) incorporating operational amplifiers. | 1 | |
| F.5.3 | Derive an expression for the gain of an inverting amplifier and for a non-inverting amplifier. | 3 | Students should be aware of the virtual earth approximation. |
| F.5.4 | Describe the use of an operational amplifier circuit as a comparator. | 2 | Students will be expected to draw appropriate circuits. Output devices for comparator circuits may include light-emitting diodes (LEDs) and buzzers. |
| F.5.5 | Describe the use of a Schmitt trigger for the reshaping of digital pulses. | 2 | |
| F.5.6 | Solve problems involving circuits incorporating operational amplifiers. | 3 | |


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## HL F6 The mobile phone system

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| F.6.1 | State that any area is divided into a number of cells (each with its own base station) to which is allocated a range of frequencies. | 1 | Students should know that frequencies are allocated so as to avoid overlap between cells. |
| F.6.2 | Describe the role of the cellular exchange and the public switched telephone network (PSTN) in communications using mobile phones. | 2 | The role of the cellular exchange in the selection and monitoring of base stations and the allocation of channels should be understood. |
| F.6.3 | Discuss the use of mobile phones in multimedia communication. | 3 | |
| F.6.4 | Discuss the moral, ethical, economic, environmental and international issues arising from the use of mobile phones. | 3 | |

# Option G: Electromagnetic waves (15/22 hours)

**Aim 7:** There are many computer simulations of interference, diffraction and other wave phenomena.

**TOK:** This is a good opportunity to show how the unifying concept of waves leads to a powerful synthesis.

**Core material:** G1–G4 are core material for SL and HL (15 hours).

**Extension material:** G5–G6 are extension material for HL only (7 hours).

## G1 The nature of EM waves and light sources

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Nature and properties of EM waves** | | | |
| G.1.1 | Outline the nature of electromagnetic (EM) waves. | 2 | Students should know that an oscillating electric charge produces varying electric and magnetic fields.<br>Students should know that electromagnetic waves are transverse waves and all have the same speed in a vacuum.<br>**Aim 8 and TOK:** Students could consider the possible health hazards associated with transmission lines. |

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| G.1.2 | Describe the different regions of the electromagnetic spectrum. | 2 | Students should know the order of magnitude of the frequencies and wavelengths of different regions, and should also be able to identify a source for each region. |
| G.1.3 | Describe what is meant by the dispersion of EM waves. | 2 | |
| G.1.4 | Describe the dispersion of EM waves in terms of the dependence of refractive index on wavelength. | 2 | No quantitative discussion is required. |
| G.1.5 | Distinguish between transmission, absorption and scattering of radiation. | 2 | |
| G.1.6 | Discuss examples of the transmission, absorption and scattering of EM radiation. | 2 | Students should study the effect of the Earth's atmosphere on incident EM radiation. This will lead to simple explanations for the blue colour of the sky, red sunsets or sunrises, the effect of the ozone layers, and the effect of increased $CO_2$ in the atmosphere. This links with 8.5.6. |
| **Lasers** | | | |
| G.1.7 | Explain the terms monochromatic and coherent. | 3 | |
| G.1.8 | Identify laser light as a source of coherent light. | 2 | |
| G.1.9 | Outline the mechanism for the production of laser light. | 2 | Students should be familiar with the term population inversion. |
| G.1.10 | Outline an application of the use of a laser. | 2 | Students should appreciate that lasers have many different applications. These may include:<br>• medical applications<br>• communications<br>• technology (bar-code scanners, laser disks)<br>• industry (surveying, welding and machining metals, drilling tiny holes in metals)<br>• production of CDs<br>• reading and writing CDs, DVDs, etc. |


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## G2 Optical instruments

**6 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| G.2.1 | Define the terms *principal axis*, *focal point*, *focal length* and *linear magnification* as applied to a converging (convex) lens. | 1 | |
| G.2.2 | Define the *power* of a *convex lens* and the *dioptre*. | 1 | |
| G.2.3 | Define *linear magnification*. | 1 | |
| G.2.4 | Construct ray diagrams to locate the image formed by a convex lens. | 3 | Students should appreciate that all rays incident on the lens from the object will be focused, and that the image will be formed even if part of the lens is covered. |
| G.2.5 | Distinguish between a real image and a virtual image. | 2 | |
| G.2.6 | Apply the convention "real is positive, virtual is negative" to the thin lens formula. | 2 | |
| G.2.7 | Solve problems for a single convex lens using the thin lens formula. | 3 | |
| **The simple magnifying glass** | | | |
| G.2.8 | Define the terms *far point* and *near point* for the unaided eye. | 1 | For the normal eye, the far point may be assumed to be at infinity and the near point is conventionally taken as being a point 25 cm from the eye. |
| G.2.9 | Define *angular magnification*. | 1 | |
| G.2.10 | Derive an expression for the angular magnification of a simple magnifying glass for an image formed at the near point and at infinity. | 3 | |
| **The compound microscope and astronomical telescope** | | | |
| G.2.11 | Construct a ray diagram for a compound microscope with final image formed close to the near point of the eye (normal adjustment). | 3 | Students should be familiar with the terms objective lens and eyepiece lens. |
| G.2.12 | Construct a ray diagram for an astronomical telescope with the final image at infinity (normal adjustment). | 3 | |
| G.2.13 | State the equation relating angular magnification to the focal lengths of the lenses in an astronomical telescope in normal adjustment. | 1 | |
| G.2.14 | Solve problems involving the compound microscope and the astronomical telescope. | 3 | Problems can be solved either by scale ray diagrams or by calculation. |

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Aberrations** | | | |
| G.2.15 | Explain the meaning of spherical aberration and of chromatic aberration as produced by a single lens. | 3 | |
| G.2.16 | Describe how spherical aberration in a lens may be reduced. | 2 | |
| G.2.17 | Describe how chromatic aberration in a lens may be reduced. | 2 | |

## G3 Two-source interference of waves

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| G.3.1 | State the conditions necessary to observe interference between two sources. | 1 | |
| G.3.2 | Explain, by means of the principle of superposition, the interference pattern produced by waves from two coherent point sources. | 3 | The effect may be illustrated using water waves and sound waves in addition to EM waves. |
| G.3.3 | Outline a double-slit experiment for light and draw the intensity distribution of the observed fringe pattern. | 2 | This should be restricted to the situation where the slit width is small compared to the slit separation so that diffraction effects of a single slit on the pattern are not considered. |
| G.3.4 | Solve problems involving two-source interference. | 3 | |

## G4 Diffraction grating

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Multiple-slit diffraction** | | | |
| G.4.1 | Describe the effect on the double-slit intensity distribution of increasing the number of slits. | 2 | |
| G.4.2 | Derive the diffraction grating formula for normal incidence. | 3 | |
| G.4.3 | Outline the use of a diffraction grating to measure wavelengths. | 2 | Use of the spectrometer is not included. |
| G.4.4 | Solve problems involving a diffraction grating. | 3 | |

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## HL G5 X-rays

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| G.5.1 | Outline the experimental arrangement for the production of X-rays. | 2 | A Coolidge tube is sufficient. Students should understand how the intensity and hardness of the X-ray beam are controlled. |
| G.5.2 | Draw and annotate a typical X-ray spectrum. | 2 | Students should be able to identify the continuous and characteristic features of the spectrum and the minimum wavelength limit. |
| G.5.3 | Explain the origins of the features of a characteristic X-ray spectrum. | 3 | |
| G.5.4 | Solve problems involving accelerating potential difference and minimum wavelength. | 3 | |
| **X-ray diffraction** | | | |
| G.5.5 | Explain how X-ray diffraction arises from the scattering of X-rays in a crystal. | 3 | This may be illustrated using 3 cm equipment. |
| G.5.6 | Derive the Bragg scattering equation. | 3 | |
| G.5.7 | Outline how cubic crystals may be used to measure the wavelength of X-rays. | 2 | Students should be aware of the fact that the structure of DNA was discovered by means of X-ray diffraction. |
| G.5.8 | Outline how X-rays may be used to determine the structure of crystals. | 2 | |
| G.5.9 | Solve problems involving the Bragg equation. | 3 | |

## HL G6 Thin-film interference

**3 hours**

**Aim 7:** Computer simulations are useful here.

**Aim 8:** Some uses of thin films raise environmental and ethical issues (see G.6.10 and G.6.11).

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Wedge films** | | | |
| G.6.1 | Explain the production of interference fringes by a thin air wedge. | 3 | Students should be familiar with the terms equal inclination and equal thickness. |
| G.6.2 | Explain how wedge fringes can be used to measure very small separations. | 3 | Applications include measurement of the thickness of the tear film on the eye and oil slicks. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| G.6.3 | Describe how thin-film interference is used to test optical flats. | 2 | |
| G.6.4 | Solve problems involving wedge films. | 3 | |
| **Parallel films** | | | |
| G.6.5 | State the condition for light to undergo either a phase change of π, or no phase change, on reflection from an interface. | 1 | |
| G.6.6 | Describe how a source of light gives rise to an interference pattern when the light is reflected at both surfaces of a parallel film. | 2 | |
| G.6.7 | State the conditions for constructive and destructive interference. | 1 | |
| G.6.8 | Explain the formation of coloured fringes when white light is reflected from thin films, such as oil and soap films. | 3 | |
| G.6.9 | Describe the difference between fringes formed by a parallel film and a wedge film. | 2 | |
| G.6.10 | Describe applications of parallel thin films. | 2 | Applications should include:<br>• design of non-reflecting radar coatings for military aircraft<br>• measurement of thickness of oil slicks caused by spillage<br>• design of non-reflecting surfaces for lenses (blooming), solar panels and solar cells. |
| G.6.11 | Solve problems involving parallel films. | 3 | These will include problems involving the application of thin films. |

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# Syllabus details—Options HL

These options are available at HL only.

# Option H: Relativity (22 hours)

**TOK:** This is an opportunity to introduce the concept of a paradigm shift in relation to scientific understanding. The role of theories and their testing by experiment is crucial here. The meaning of time, the concepts of time dilation and length contraction, the absolute value of the velocity of EM waves are all stimulating ideas for discussion.

## HL H1 Introduction to relativity

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Frames of reference** | | | |
| H.1.1 | Describe what is meant by a frame of reference. | 2 | |
| H.1.2 | Describe what is meant by a Galilean transformation. | 2 | |
| H.1.3 | Solve problems involving relative velocities using the Galilean transformation equations. | 3 | |

## HL H2 Concepts and postulates of special relativity

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| H.2.1 | Describe what is meant by an inertial frame of reference. | 2 | |
| H.2.2 | State the two postulates of the special theory of relativity. | 1 | |
| H.2.3 | Discuss the concept of simultaneity. | 3 | Students should know that two events occurring at different points in space and which are simultaneous for one observer cannot be simultaneous for another observer in a different frame of reference. |

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## HL H3 Relativistic kinematics

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Time dilation** | | | |
| H.3.1 | Describe the concept of a light clock. | 2 | Only a very simple description is required here. For example, a beam of light reflected between two parallel mirrors may be used to measure time. |
| H.3.2 | Define *proper time interval*. | 1 | |
| H.3.3 | Derive the time dilation formula. | 3 | Students should be able to construct a simple derivation of the time dilation formula based on the concept of the light clock and the postulates of relativity. |
| H.3.4 | Sketch and annotate a graph showing the variation with relative velocity of the Lorentz factor. | 3 | |
| H.3.5 | Solve problems involving time dilation. | 3 | |
| **Length contraction** | | | |
| H.3.6 | Define *proper length*. | 1 | |
| H.3.7 | Describe the phenomenon of length contraction. | 2 | The derivation of the length contraction formula is not required. |
| H.3.8 | Solve problems involving length contraction. | 3 | |

## HL H4 Some consequences of special relativity

**4 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The twin paradox** | | | |
| H.4.1 | Describe how the concept of time dilation leads to the "twin paradox". | 2 | Different observers' versions of the time taken for a journey at speeds close to the speed of light may be compared.<br>Students should be aware that, since one of the twins makes an outward and return journey, this is no longer a symmetrical situation for the twins. |
| H.4.2 | Discuss the Hafele–Keating experiment. | 3 | |
| **Velocity addition** | | | |
| H.4.3 | Solve one-dimensional problems involving the relativistic addition of velocities. | 3 | The derivation of the velocity addition formula is not required. |


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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Mass and energy** | | | |
| H.4.4 | State the formula representing the equivalence of mass and energy. | 1 | |
| H.4.5 | Define *rest mass*. | 1 | Students should be aware that rest mass is an invariant quantity. Students should be familiar with the unit MeV $c^{-2}$ for mass. |
| H.4.6 | Distinguish between the energy of a body at rest and its total energy when moving. | 2 | |
| H.4.7 | Explain why no object can ever attain the speed of light in a vacuum. | 3 | |
| H.4.8 | Determine the total energy of an accelerated particle. | 3 | Students should be able, for example, to calculate the total energy of an electron after acceleration through a known potential difference. |

## HL H5 Evidence to support special relativity

**3 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| H.5.1 | Discuss muon decay as experimental evidence to support special relativity. | 3 | |
| H.5.2 | Solve problems involving the muon decay experiment. | 3 | |
| H.5.3 | Outline the Michelson–Morley experiment. | 2 | Students should be able to outline the principles of the Michelson interferometer using a simple sketch of the apparatus. |
| H.5.4 | Discuss the result of the Michelson–Morley experiment and its implication. | 3 | The implication that the ether does not exist and that the result is consistent with the constancy of the speed of light is the accepted explanation. |
| H.5.5 | Outline an experiment that indicates that the speed of light in vacuum is independent of its source. | 2 | Students should be familiar with pion decay experiments involving the decay of a fast-moving pion into two gamma-ray (γ-ray) photons. |

## HL H6 Relativistic momentum and energy

**2 hours**

Derivation of the relativistic momentum and energy formulae will not be examined.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| H.6.1 | Apply the relation for the relativistic momentum $p = \gamma m_0 u$ of particles. | 2 | Students should be familiar with momentum expressed in the unit MeV $c^{-1}$. |
| H.6.2 | Apply the formula $E_K = (\gamma - 1) m_0 c^2$ for the kinetic energy of a particle. | 2 | |

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| H.6.3 | Solve problems involving relativistic momentum and energy. | 3 | Students should be able to calculate, for example, the kinetic energy, total energy, speed and momentum of an accelerated particle and for particles produced in reactions. |

## HL H7 General relativity

**4 hours**

This section is intended as an introduction to the concepts of general relativity and is non-mathematical in its approach.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **The equivalence principle** | | | |
| H.7.1 | Explain the difference between the terms gravitational mass and inertial mass. | 3 | |
| H.7.2 | Describe and discuss Einstein's principle of equivalence. | 3 | Students should be familiar with Einstein's closed elevator "thought experiment". |
| H.7.3 | Deduce that the principle of equivalence predicts bending of light rays in a gravitational field. | 3 | |
| H.7.4 | Deduce that the principle of equivalence predicts that time slows down near a massive body. | 3 | |
| **Spacetime** | | | |
| H.7.5 | Describe the concept of spacetime. | 2 | |
| H.7.6 | State that moving objects follow the shortest path between two points in spacetime. | 1 | |
| H.7.7 | Explain gravitational attraction in terms of the warping of spacetime by matter. | 3 | |
| **Black holes** | | | |
| H.7.8 | Describe black holes. | 2 | Students should know that black holes are a region of spacetime with extreme curvatures due to the presence of a mass. |
| H.7.9 | Define the term *Schwarzschild radius*. | 1 | |
| H.7.10 | Calculate the Schwarzschild radius. | 2 | |
| H.7.11 | Solve problems involving time dilation close to a black hole. | 3 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Gravitational red-shift** | | | |
| H.7.12 | Describe the concept of gravitational red-shift. | 2 | Students should be aware that gravitational red-shift is a prediction of the general theory of relativity. |
| H.7.13 | Solve problems involving frequency shifts between different points in a uniform gravitational field. | 3 | |
| H.7.14 | Solve problems using the gravitational time dilation formula. | 3 | |

## HL H8 Evidence to support general relativity

**1 hour**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| H.8.1 | Outline an experiment for the bending of EM waves by a massive object. | 2 | An outline of the principles used in, for example, Eddington's measurements during the 1919 eclipse of the Sun is sufficient.<br>**Aim 8:** The ethical behaviour of Eddington and the limitations of data can be addressed here. |
| H.8.2 | Describe gravitational lensing. | 2 | |
| H.8.3 | Outline an experiment that provides evidence for gravitational red-shift. | 2 | The Pound–Rebka experiment (or a suitable alternative, such as the shift in frequency of an atomic clock) and the Shapiro time delay experiments are sufficient. |

# Option I: Medical physics (22 hours)

## HL I1 The ear and hearing

**6 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| I.1.1 | Describe the basic structure of the human ear. | 2 | The structure should be limited to those features affecting the physical operation of the ear. |
| I.1.2 | State and explain how sound pressure variations in air are changed into larger pressure variations in the cochlear fluid. | 3 | This can be dealt with in terms of the different areas of the eardrum and oval window, together with the lever action of the ossicles. Although the concept of impedance matching is not formally required, students should appreciate that, without a mechanism for pressure transformation between media of different densities (air and fluid), most sound would be reflected, rather than transmitted into the cochlear fluid. |

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| I.1.3 | State the range of audible frequencies experienced by a person with normal hearing. | 1 | |
| I.1.4 | State and explain that a change in observed loudness is the response of the ear to a change in intensity. | 3 | |
| I.1.5 | State and explain that there is a logarithmic response of the ear to intensity. | 3 | |
| I.1.6 | Define *intensity* and also *intensity level* (*IL*). | 1 | |
| I.1.7 | State the approximate magnitude of the intensity level at which discomfort is experienced by a person with normal hearing. | 1 | |
| I.1.8 | Solve problems involving intensity levels. | 3 | **Aim 7, aim 8:** Data logging may be used to investigate traffic noise, etc. |
| I.1.9 | Describe the effects on hearing of short-term and long-term exposure to noise. | 2 | Students should be aware of temporary and permanent deafness, tinnitus and selective frequency losses. They should show an appreciation of the social implications of hearing loss on an individual.<br>**Aim 8:** Legislation and the moral responsibility of employers could be considered. |
| I.1.10 | Analyse and give a simple interpretation of graphs where IL is plotted against the logarithm of frequency for normal and for defective hearing. | 3 | |

## HL I2 Medical imaging

**10 hours**

Students should be able to discuss the advantages and disadvantages of various imaging techniques for particular purposes.

**Aim 7:** Students may like to consult databases of images available from teaching hospitals.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **X-rays** | | | |
| I.2.1 | Define the terms *attenuation coefficient* and *half-value thickness*. | 1 | Students may study these concepts in the context of a parallel beam of X-rays but should appreciate their wider application. |
| I.2.2 | Derive the relation between attenuation coefficient and half-value thickness. | 3 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| I.2.3 | Solve problems using the equation $I = I_0 e^{-\mu x}$. | 3 | Students may use simulation exercises to study X-ray attenuation. |
| I.2.4 | Describe X-ray detection, recording and display techniques. | 2 | Students should be aware of photographic film, enhancement, electronic detection and display. |
| I.2.5 | Explain standard X-ray imaging techniques used in medicine. | 3 | Students should appreciate the causes of loss of sharpness and of contrast in X-ray imaging. They should be familiar with techniques for improving sharpness and contrast. |
| I.2.6 | Outline the principles of computed tomography (CT). | 2 | Students should be able to describe how a three-dimensional image is constructed. |
| **Ultrasound** | | | |
| I.2.7 | Describe the principles of the generation and the detection of ultrasound using piezoelectric crystals. | 2 | |
| I.2.8 | Define *acoustic impedance* as the product of the density of a substance and the speed of sound in that substance. | 1 | |
| I.2.9 | Solve problems involving acoustic impedance. | 3 | Students should understand the use of a gel on the surface of the skin. |
| I.2.10 | Outline the differences between A-scans and B-scans. | 2 | |
| I.2.11 | Identify factors that affect the choice of diagnostic frequency. | 2 | Students should appreciate that attenuation and resolution are dependent on frequency. |
| **NMR and lasers** | | | |
| I.2.12 | Outline the basic principles of nuclear magnetic resonance (NMR) imaging. | 2 | Students need only give a simple qualitative description of the principle, including the use of a non-uniform magnetic field in conjunction with the large uniform field. |
| I.2.13 | Describe examples of the use of lasers in clinical diagnosis and therapy. | 2 | Applications such as the use in pulse oximetry and in endoscopes should be discussed. Students should be familiar with the use of a laser as a scalpel and as a coagulator. |

## HL I3 Radiation in medicine

**6 hours**

**Aim 8:** Moral, ethical and social implications of the use of radiation should be discussed where appropriate.

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| I.3.1 | State the meanings of the terms exposure, absorbed dose, quality factor (relative biological effectiveness) and dose equivalent as used in radiation dosimetry. | 1 | Students should be able to discuss the significance of these quantities in radiation dosimetry. |
| I.3.2 | Discuss the precautions taken in situations involving different types of radiation. | 3 | Students should consider shielding, distance and time-of-exposure factors. They should be familiar with the film badge.<br>**TOK:** They should appreciate that current practice is determined from a gradual increase in available data. |
| I.3.3 | Discuss the concept of balanced risk. | 3 | **Aim 8, Int, TOK:** Students should appreciate that codes of practice have been developed for conduct involving the use of radiations. |
| I.3.4 | Distinguish between physical half-life, biological half-life and effective half-life. | 2 | Students should be able to calculate the effective half-life from the physical half-life and the biological half-life. |
| I.3.5 | Solve problems involving radiation dosimetry. | 3 | |
| I.3.6 | Outline the basis of radiation therapy for cancer. | 2 | This should include the differential effects on normal and malignant cells, as well as a description of the types of sources available. |
| I.3.7 | Solve problems involving the choice of radio-isotope suitable for a particular diagnostic or therapeutic application. | 3 | Students should be familiar with a variety of techniques. Where reference is made to a specific technique, sufficient description will be given for the student to be able to answer any questions on that technique. |
| I.3.8 | Solve problems involving particular diagnostic applications. | 3 | For example, assessment of total blood volume. Where reference is made to a specific technique, sufficient description will be given for the student to be able to answer any questions on that technique. |


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# Option J: Particle physics (22 hours)

A free CD-Rom produced by CERN (also available on the CERN web site) covers all the material in this option.

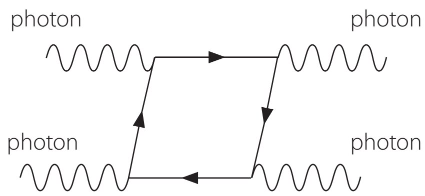
In this option, all masses are assumed to be rest masses.

**TOK:** This whole option contains a wealth of information for discussion, for example, the nature of observation, the meaning of measurement, and the meaning of evidence. How developments in one field lead to breakthroughs in another is also a fascinating topic, for example, particle physics and cosmology.

## HL J1 Particles and interactions

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Description and classification of particles** | | | |
| J.1.1 | State what is meant by an elementary particle. | 1 | Particles are called elementary if they have no internal structure, that is, they are not made out of smaller constituents. |
| J.1.2 | Identify elementary particles. | 2 | The classes of elementary particles are quarks, leptons and exchange particles. The Higgs particle could be elementary. |
| J.1.3 | Describe particles in terms of mass and various quantum numbers. | 2 | Students must be aware that particles (elementary as well as composite) are specified in terms of their mass and various quantum numbers. They should consider electric charge, spin, strangeness, colour, lepton number and baryon number. |
| J.1.4 | Classify particles according to spin. | 1 | |
| J.1.5 | State what is meant by an antiparticle. | 1 | |
| J.1.6 | State the Pauli exclusion principle. | 1 | |
| **Fundamental interactions** | | | |
| J.1.7 | List the fundamental interactions. | 1 | Since the early 1970s the electromagnetic and weak interactions have been shown to be two aspects of the same interaction, the electroweak interaction. |
| J.1.8 | Describe the fundamental interactions in terms of exchange particles. | 2 | |
| J.1.9 | Discuss the uncertainty principle for time and energy in the context of particle creation. | 3 | A simple discussion in terms of a particle being created with energy $\Delta E$ existing no longer than a time $\Delta t$ given by $\Delta E \Delta t \geq \frac{h}{4\pi}$. |
| **Feynman diagrams** | | | |
| J.1.10 | Describe what is meant by a Feynman diagram. | 2 | |

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| J.1.11 | Discuss how a Feynman diagram may be used to calculate probabilities for fundamental processes. | 3 | Numerical values of the interaction strengths do not need to be recalled. |
| J.1.12 | Describe what is meant by virtual particles. | 2 | |
| J.1.13 | Apply the formula for the range *R* for interactions involving the exchange of a particle. | 2 | Applications include Yukawa's prediction of the pion or determination of the masses of the $W^{\pm}$, $Z^{0}$ from knowledge of the range of the weak interaction. |
| J.1.14 | Describe pair annihilation and pair production through Feynman diagrams. | 2 | |
| J.1.15 | Predict particle processes using Feynman diagrams. | 3 | For example, the electromagnetic interaction leads to photon–photon scattering (that is, scattering of light by light). The particles in the loop are electrons or positrons:<br><br> |

## HL J2 Particle accelerators and detectors

**6 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| **Particle accelerators** | | | |
| J.2.1 | Explain the need for high energies in order to produce particles of large mass. | 3 | |
| J.2.2 | Explain the need for high energies in order to resolve particles of small size. | 3 | Students should know that, to resolve a particle of size *d*, the de Broglie wavelength $\lambda = \frac{h}{p}$ of the particle used to scatter from it must be of the same order of magnitude as *d*.<br>The connection with diffraction may prove useful here. |
| J.2.3 | Outline the structure and operation of a linear accelerator and of a cyclotron. | 2 | |
| J.2.4 | Outline the structure and explain the operation of a synchrotron. | 3 | Students should be able to explain how the charged beams are accelerated, why the magnetic fields must vary and why the ring has a large radius. |
| J.2.5 | State what is meant by bremsstrahlung (braking) radiation. | 1 | |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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| J.2.6 | Compare the advantages and disadvantages of linear accelerators, cyclotrons and synchrotrons. | 3 | |
| J.2.7 | Solve problems related to the production of particles in accelerators. | 3 | These include the total energy of the particle in terms of its mass and kinetic energy, and the total energy available from the collision of a particle with a stationary target. |
| **Particle detectors** | | | |
| J.2.8 | Outline the structure and operation of the bubble chamber, the photomultiplier and the wire chamber. | 2 | |
| J.2.9 | Outline international aspects of research into high-energy particle physics. | 2 | Students should be aware that governments need to collaborate to construct and operate large-scale research facilities. There are very few accelerator facilities, for example, CERN, DESY, SLAC, Fermilab and Brookhaven. Results are disseminated and shared by scientists in many countries. |
| J.2.10 | Discuss the economic and ethical implications of high-energy particle physics research. | 3 | Students should be aware that, even at the height of the Cold War, Western and Soviet scientists collaborated in the field of particle physics. |

## HL J3 Quarks

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| J.3.1 | List the six types of quark. | 1 | |
| J.3.2 | State the content, in terms of quarks and antiquarks, of hadrons (that is, baryons and mesons). | 1 | |
| J.3.3 | State the quark content of the proton and the neutron. | 1 | |
| J.3.4 | Define *baryon number* and apply the law of conservation of baryon number. | 2 | Students should know that baryon number is conserved in all reactions. |
| J.3.5 | Deduce the spin structure of hadrons (that is, baryons and mesons). | 3 | Only an elementary discussion in terms of spin "up" and spin "down" is required. |
| J.3.6 | Explain the need for colour in forming bound states of quarks. | 3 | Students should realize that colour is necessary to satisfy the Pauli exclusion principle. The fact that hadrons have no colour is a consequence of confinement. |
| J.3.7 | State the colour of quarks and gluons. | 1 | |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| J.3.8 | Outline the concept of strangeness. | 2 | It is sufficient for students to know that the strangeness of a hadron is the number of anti-strange quarks minus the number of strange quarks it contains.<br>Students must be aware that strangeness is conserved in strong and electromagnetic interactions, but not always in weak interactions. |
| J.3.9 | Discuss quark confinement. | 3 | Students should know that isolated quarks and gluons (that is, particles with colour) cannot be observed. The strong (colour) interaction increases with separation. More hadrons are produced when sufficient energy is supplied to a hadron in order to isolate a quark. |
| J.3.10 | Discuss the interaction that binds nucleons in terms of the colour force between quarks. | 3 | It is sufficient to know that the interaction between nucleons is the residual interaction between the quarks in the nucleons and that this is a short-range interaction. |

## HL J4 Leptons and the standard model

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| J.4.1 | State the three-family structure of quarks and leptons in the standard model. | 1 | Students should know that the standard model is the presently accepted theory describing the electromagnetic and weak interactions of quarks and leptons. |
| J.4.2 | State the lepton number of the leptons in each family. | 1 | |
| J.4.3 | Solve problems involving conservation laws in particle reactions. | 3 | Students should know that electric charge, total energy, momentum, baryon number and family lepton number are conserved in all particle reactions. Strangeness is conserved in strong and electromagnetic interactions, but not always in weak interactions. |
| J.4.4 | Evaluate the significance of the Higgs particle (boson). | 3 | Students should know that particles acquire mass as a result of interactions involving the Higgs boson. |

## HL J5 Experimental evidence for the quark and standard models

**5 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| J.5.1 | State what is meant by deep inelastic scattering. | 1 | |
| J.5.2 | Analyse the results of deep inelastic scattering experiments. | 3 | Students should appreciate that these experiments provide evidence for the existence of quarks, gluons and colour. |

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| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| J.5.3 | Describe what is meant by asymptotic freedom. | 2 | It is sufficient for students to know that the strength of the strong interaction decreases as the energy available for the interaction increases. |
| J.5.4 | Describe what is meant by neutral current. | 2 | A simple description in terms of processes involving $Z^0$ exchange is sufficient. |
| J.5.5 | Describe how the existence of a neutral current is evidence for the standard model. | 2 | Students should know that only the standard model predicts weak interaction processes involving the exchange of a massive, neutral particle (the $Z^0$ boson). |

## HL J6 Cosmology and strings

**2 hours**

| | Assessment statement | Obj | Teacher's notes |
|---|---|---|---|
| J.6.1 | State the order of magnitude of the temperature change of the universe since the Big Bang. | 1 | The temperature of the universe was $10^{32}$ K at $10^{-43}$ s after the Big Bang and is 2.7 K at present. |
| J.6.2 | Solve problems involving particle interactions in the early universe. | 3 | For example, problems will include calculation of the temperature:<br>• at which production of electron–positron pairs becomes possible<br>• at which nucleosynthesis can take place<br>• when the universe becomes transparent to radiation. |
| J.6.3 | State that the early universe contained almost equal numbers of particles and antiparticles. | 1 | |
| J.6.4 | Suggest a mechanism by which the predominance of matter over antimatter has occurred. | 3 | A simple explanation in terms of the impossibility of photons materializing into particle–antiparticle pairs once the temperature fell below a certain value is all that is required. |
| J.6.5 | Describe qualitatively the theory of strings. | 2 | Students should be aware that the failure to reconcile gravitation with quantum theory has created the idea of a string as the fundamental building block of matter. The known fundamental particles are modes of vibration of the string similar to the harmonics of an ordinary vibrating string. |

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# Mathematical requirements

All physics students need to be familiar with a range of mathematical techniques. The abilities described here are not prerequisites for undertaking a Diploma Programme physics course, but they do represent the skills expected of examination candidates by the end of such a course. (The requirements written in **bold** apply only to **higher level** students.)

## Arithmetic and computation

- Make calculations involving addition, subtraction, multiplication and division.
- Recognize and use expressions in decimal and standard form (scientific) notation.
- Use calculators to evaluate: **exponentials**; reciprocals; roots; logarithms to base 10 (lg); **logarithms to base e (ln)**; powers; arithmetic means; degrees; radians; natural sine, cosine and tangent functions and their inverses.
- Express fractions as percentages and vice versa.

## Algebra

- Change the subject of an equation by manipulation of the terms, including integer and fractional indices and square roots.
- Solve simple algebraic equations, and **simultaneous linear equations involving two variables**.
- Substitute numerical values into algebraic equations.
- Comprehend the meanings of (and use) the symbols $/, <, >, \geq, \leq, \times, \approx, |x|, \propto, \Delta x$.

## Geometry and trigonometry

- Recall the formulae for, and calculate areas of, right-angled and isosceles triangles, circumferences and areas of circles, volumes of rectangular blocks, cylinders and spheres, and surface areas of rectangular blocks, cylinders and spheres.
- Use Pythagoras' theorem, similarity of triangles and recall that the angles of a triangle add up to 180° (and of a rectangle, 360°).
- Understand the relationship between degrees and radians, and translate from one to the other.
- Recall the small-angle approximations.

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